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CONTRIBUTIONS

FROM THE

SANITARY RESEARCH LABORATORY

AND

SEWAGE EXPERIMENT STATION

VOL. III

REPRINTED PAPERS

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PREFATORY NOTE.

Volume I. of "Contributions from the Sanitary Research Lal oratory and Sewage Experiment Station of the Massachusett Institute of Technology" originally appeared in Supplement Nc I. (May, 1905) of the *Journal of Infectious Diseases.* A limite edition was also issued and distributed separately. This editioı was quickly exhausted by an unexpectedly large demand, bu copies of the original publication, the Supplement mentione above, may at this writing still be purchased from the publishe of the *Journal of Infectious Diseases*, Chicago, Ill.

Volume II. of the "Contributions," the most important o the publications of the Laboratory and Station up to this point is now in press and will shortly be issued in a large edition a Water Supply and Irrigation paper No. 185 by the United State Geological Survey. It will include a complete account of ou experiments on the purification of sewage for the years 1903-1905, together with an historical digest of the sewage-disposa problem in Europe and America, and of the means proposed fo its scientific solution.

Application for copies of Volume II. should be made to th Director of the United States Geological Survey, Washington D. C.

The present Volume (Vol. III. of the series) is a collection o miscellaneous papers on sewage disposal and other sanitary sub jects published in various technical or scientific journals by mem bers of the staff of the Laboratory and Station in 1905 and 1906 During this time, thanks to the continued generosity of the anony mous donor, the work of investigation has been steadily continued the principal workers having been, as before, Assistant Professo C.-E. A. Winslow, Biologist-in-Charge, and Earle B. Phelps, S.B. Research Chemist and Bacteriologist.

W. T. SEDGWICK,
Director

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
BOSTON, August, 1906.

THE READJUSTMENT OF EDUCATION AND RESEARCH IN HYGIENE AND SANITATION.

By WILLIAM T. SEDGWICK,

Professor of Biology and Director of the Sanitary Research
Laboratory and Sewage Experiment Station, Mass.
Institute of Technology, Boston.

THE READJUSTMENT OF EDUCATION AND RESEARCH I HYGIENE AND SANITATION.

BY WILLIAM T. SEDGWICK,

PROFESSOR OF BIOLOGY AND DIRECTOR OF THE SANITARY RESEARCH LABORATOR AND SEWAGE EXPERIMENT STATION, MASS. INSTITUTE OF TECHNOLOGY, BOSTON.

In Herbert Spencer's well known definition, continuous adjustmen is seized upon as the essential characteristic of life, and in any vita enterprise such as business, government, education or research, frequent, if not continuous, adjustments and readjustments are indispensable. In the present paper I propose to inquire whether the time has not come for a readjustment of our definitions and methods of research and education in hygiene and sanitation. And if it turns out, as I think it will, that such is the case, I shall venture to indicate some of the steps required to be taken in order to bring about readjustment.

We shall gain in perspective more than we lose in time if we recall briefly how the conditions that now prevail orignated. In doing this we need not go further back than Pettenkofer, for with him, his associates and successors, scientific hygiene and sanitation as these exist to-day began. It is true that the Greeks valued the *mens sana in corpore sano* and earnestly strove to attain it. It is true that Combe and Kingsley and many other English laymen did good public service in the middle of the nineteenth century by preaching that cleanliness, public as well as private, is next to godliness. It is true that Johannes Müller and his successors laid the basis of a rational personal hygiene by working out the basis of a rational physiology. But the first to bring to bear upon hygiene in all its branches, so far as then known, the exact methods of chemistry, physics and physiology; the first to emphasize adequately the importance of good water supplies and especially of good sewerage; the first to examine scientificaly the ground, and ground air, and ground water, the porosity of the walls of houses and, in general, those environmental aspects of hygiene to which we give to-day the special name "sanitation" — was Max von Pettenkofer, Professor in the University of Munich, with his associates and successors.

In recognition of Pettenkofer's pioneer work and the importance of the science which it represents, a new institute, the Hygienic Institute, of which Pettenkofer was made the Director, was added to those already existing in the University of Munich and this building, located near the Physiological Institute and like that situated upon a street which now bears the name of Pettenkofer, should be a shrine of pilgrimage for all hygienists both as Pettenkofer's laboratory and as the first of a long series of hygienic institutes established since then all over the civilized world. Up to this time Pettenkofer had worked in the physiological institute with his friend and colleague Voit, so that the new science of Hygiene may be said to have sprung directly as a branch from Physiology, then as now, a fundamental member of the group of medical sciences. The connection of hygiene with medicine, or at least with physiology, is thus ancestral and phylogenetic. But while hygiene began, and must always begin, with physiology, it did not and cannot end there. Pettenkofer's own work even, soon led him into questions of public hygiene, involving, for example, chemistry, physics and engineering, into air analysis, soil physics and problems of water supply and sewage. And so urgent and promising were these problems of the public health that the physiological problems of individual or personal hygiene soon played but a small part in the work of the new Institute.

This tendency to depart from physiology thus early discoverable in this first hygienic institute, was a recognition — perhaps an unconscious recognition — of a fact which has since become perfectly clear, namely, that the sphere of hygiene is naturally separable into two distinct hemispheres, one dealing directly and chiefly with individuals or masses of individuals, the other directly and chiefly with their environment. And inasmuch as it is this tendency and this differentiation which have, as it were, thrown out of adjustment our earlier methods of research and education in hygiene, making necessary that readjustment which it is the purpose of this paper to propose and promote, we must before going further observe carefully how far this differentiation has proceeded already, and how far it is likely to go in the future.

If we examine any recent textbook professing to cover the whole field of hygiene we cannot fail to be struck with the variety, not to say incongruity of the topics treated. This is especially true of the German textbooks, taken as a whole, but is also characteristic of some English and American textbooks. Subjects as unlike as muscular exercise and street cleaning, or foods and railway sanitation, are grouped together, so that the reader who turns the pages cannot help wondering if hygiene is not the most comprehensive of sciences and a hygienist the broadest of men. Moreover a student of the science of health soon hears the words "sanitary" and "sanitation" as well as "hygienic" and "hygiene" and may well ask exactly what each and all mean. If he be interested in research rather than education he will meet not onl with hygienic institutes, but also sewage experiment stations, foo and drug laboratories, and laboratories of sanitary research; laboratories of sanitary chemistry, water analysis, food analysis, etc. Thes various differentiations are largely the outcome of the marvelous additions to our knowledge, and especially to our knowledge of the environment, within the last half century. Almost every discovery in science almost every advance in engineering, has contributed some fact or condition of practical interest or importance to general hygiene. Th pressure of population, the migration from country to city, labor-saving machinery, the growth of traveling, the enrichment of our dietarie the factory system, high buildings, cold storage, and a thousand othe modifications of our ways of living,—all these have opened up problem of hygiene previously either non-existent or unknown. To-day we ar also beginning to appreciate the importance and power of the protoplasmic human mechanism, which has to struggle for existence an success under these various conditions, and to look to the physiologist for a more intimate knowledge of its normal operation.

Meantime, in America at least, research in hygiene is comparativel sporadic if not desultory, and educational opportunities are few an unsatisfactory. Hygiene is allowed only a modicum of time in ou medical schools and little or no place in schools of engineering. An yet its importance to modern society is unquestioned. Never before ha a higher value been set upon the working efficiency of the human machine. Never before have preventive medicine, hygiene or sanitatio occupied so high a place in the public esteem. Why is it, then, we ma well ask, that medical schools pay so little attention to a subject so important and at the same time so closely connected historically an practically with medical science? The answer to this question will, believe, establish the truth of my thesis that readjustment is required and will also reveal some of the steps required to bring about suc readjustment.

In spite of its admitted importance, hygiene occupies only a ver small place in our medical schools, partly, I believe, because *sanitatio* has become so large a part of hygiene, and sanitation belongs in school of engineering; and partly because for medical men there are, in ou country, very few attractive positions in the applications of hygiene Let us consider the first point more carefully. It is to-day absurd fo the average well trained medical student to think of becoming an exper in such branches of hygiene as water supply, sewerage, heating an ventilation, street building, cleaning and watering, garbage collectio and disposal, gas and other forms of light supply, ice supply, mill supply, the abatement of nuisances, etc. These belong rather to the sanitary engineer, sanitary chemist and sanitary biologist; to sanitation rather than hygiene.

Closer to the physician's own work, and yet almost a science in themselves, are the problems of personal hygiene, muscular exercise, sleep, foods and feeding, bathing, clothing, mental work, and the like. Half way between personal and public hygiene, lie such subjects as school hygiene and school sanitation, epidemiology, quarantine, the control of foods and drugs. If the modern medical student can find time for a thorough acquaintance with bacteriology and serum science he is probably doing all that we ought to expect of a well trained beginner in medicine or surgery. The difficulty here described suggests its own remedy. Why not begin in our readjustment by making a sharp distinction between the hygiene of the individual and that of the environment, keeping for the former the older, broader and historic term *hygiene,* and giving to the latter the term already almost universally applied to it (unless in Germany), namely *sanitation.* Next, why not frankly give up the pretense of teaching in medical schools of more than the most general and elementary principles of water supply, sewerage, heating and ventilation, street construction, street cleaning, street watering, plumbing, gas supply, ice supply, milk supply, and the purity of foods and drugs, leaving these to sanitarians — engineers, chemists, and biologists. Freed from these subjects, courses in hygiene might be given in medical schools which should be practically valuable to medical men, dealing as these should chiefly with its personal aspects, and yet involving many of the most important matters relating to the public health. Such courses would be essentially medical, or at least physiological, and are to-day greatly needed. I think I am within the truth in saying that in some engineering schools sanitation is to-day better taught than personal hygiene is in any medical school; and this surely ought not to be, and need not be, true.

As for research, it is idle to expect the ordinary medical man to be greatly interested in or to spend much time upon the detailed problems of water or sewage purification, even if he has — as he generally has not — the requisite training. We must expect this work to be done by engineers, chemists, and biologists, and not by physicians. And its teaching belongs in schools of science and engineering rather than in medical schools.

At the same time another and fundamental readjustment is sorely needed, which, if it could be effected, would do more to promote good teaching and research in hygiene and sanitation than any other one thing. This is the establishment of *permanent, well-paid positions* in the service of the public health. I am not sanguine that this readjustment — the most fundamental of all, and one which, if it could be mad would speedily bring about the others — is either easy or imminent, an yet I believe that we should never cease for an instant to proclai its necessity or to work for it. Somehow or other, we must in Americ secure a large group of well-paid public health officers who shall hav powers of more than local jurisdiction or at least more than local visitation, criticism and advice; who shall be supplied with laboratories an other means of experiment and investigation; and who shall be able an willing to call to their aid and co-operation, sanitary engineers, sanitary chemists and sanitary biologists. These public health officers wi naturally be medical men, but they will not be ordinary medical me They must be specially trained for the work; they must know more o infectious than of chronic diseases; more of medicine than of surgery they must be thoroughly equipped in epidemiology and must have general but sound elementary knowledge of sanitation; they shoul know and use statistics; and above all they should possess tact, courag and firmness. When the places for such men are provided the me will soon be found. A medical school will then gladly give course not only in hygiene but in public health, such as will prepare good ca didates. I believe it to be our first duty to work for the establishme of such public health positions, and all that is needed to secure the is a general readiness to surrender some local pride and some local i portance, for the sake of national progress, mutual benefit, and th advancement of science.

Meantime we must look to our universities and technical schools f the maintenance of the very best hygienic laboratories and sanitar experiment stations which they can afford, and to our states an cities for the best that money can buy. Even these are not enoug Brief but comprehensive courses in the theory and practice of hygien and especially personal hygiene, should be offered in all medical school and in the theory and practice, of sanitation, in our technical an scientific schools. In this way the road would be open to all — ph sicians, scientists and engineers — to become grounded in the gener principles of hygiene, while for those whose tastes and abilities le them to go further, the research laboratories already mentioned, and th positions referred to, would offer an incentive and hold out inviting an honorable careers. It is hard to think of any consummation at prese more devoutly to be wished for in the United States or more certain t redound to the promotion of the public health and the public welfar

Politics must also be wholly eliminated from our boards of healt both state and municipal. There is no republican method of vaccinatio no democratic plan of street cleaning. And places on boards of health must not be used as rewards of political activity. The time, if it ever existed, has gone by when a proper board of health can be made up of a political doctor, a political saloon-keeper and a political nobody; for no well-trained and self-respecting expert in hygiene or sanitation can or will long remain in the dubious and uncertain service of such weak, incompetent or shifty characters.

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THE SCIENTIFIC DISPOSAL OF CITY SEWAGE: HISTORICAL DEVELOPMENT AND PRESENT STATUS OF THE PROBLEM

By C.-E. A. WINSLOW

(Read October 12, 1905)

THE disposal of waste is a fundamental problem for all livin organisms. As the body takes in food and builds it up into its ow wonderful structure, so it must continually break down and give o waste products, which, as a rule, if they accumulate prove poisono to the organism itself. And as this is the case with the individual, is it still more the case when large numbers of organisms are close congregated together in communities. Nevertheless the attempt scientific waste disposal is a comparatively recent one. It really dat from the epoch-making report of the Health of Towns Commission Great Britain in 1844, which revealed such astonishing conditions wit regard to the decomposing organic matter, and the filth of all kin which had accumulated in British cities, that it aroused British sanit rians to a strong movement for the amelioration of these condition and led to the development of the filth theory of disease — the theo that disease is bred in heaps of decomposing filth. This theory we no know to be wrong in its essential assumption that infective material created *de novo* by decaying organic matter; yet it was right in layi emphasis on filth as a carrier of disease. The wonderful administrative work of the British sanitarians, acting on this partially erroneous theory, effected the greatest sanitary progress which has probably ever been known; so that whereas in 1815 the sewers of London were simply drains to carry off the storm water, the discharge of sewage into them being forbidden by law, in 1847, only three years after the report of the Health of Towns Commission, it was made obligatory to discharge all sewage into those drains.

The water carriage system, in which the sewage is diluted as promptly as possible with a large volume of water, was quickly introduced in England, and has since followed in other countries. Thus the problem of disposal was shifted one step away from the individual; instead of the individual having a small amount of waste to dispose of, the municipality has now a very much larger problem on its hands — the disposal of all the waste materials diluted with a great volume of water. For example, in Boston, on one side of the city, known as the South Metropolitan District, it is necessary in every year to dispose in some way of 1,600 tons of nitrogen as free ammonia alone, representing an enormous quantity of organic matter; and the problem is made so much more difficult by reason of the fact that the organic matter is diluted with thirty billion gallons of water.

In American sewages we find only one part in 1,000 of solid matter; in other words, there are 999 parts of water to be handled, or somewhat more than that, for every part of solid matter. The dangerous elements making up the single part in 1,000 with which we are particularly concerned in sewage disposal may be classed under three heads: organic matter, mineral matter, and bacteria. The mineral matter is harmful only under exceptional conditions, when large amounts of industrial wastes enter the sewers, and need not be considered tonight. The bacteria may be harmful when the sewage is so discharged as to reach some source of food or water supply. In the case of the water supply it is hardly fair to expect protection from the sewage expert. It is a very difficult matter indeed to produce a germ-free effluent by any process of sewage disposal, and we are now taking the position that no surface water should be used for drinking purposes without being filtered. So I think sewage experts have a right to feel that the responsibility for disease caused by the discharge of sewage into water rests most heavily upon the water supply experts. This general proposition must be modified in the special case where sewage is discharged into ponds and estuaries from which shellfish are taken. Here there can be n question of purifying the shellfish. It is necessary either to abando the taking of shellfish from such waters or to purify the sewage i such a way as to remove the disease germs. This is a problem whic may prove of increasing importance during the next few years, an which may make it necessary to produce a sterile effluent, or, at least one free from pathogenic bacteria. As a rule, however, in questions o sewage disposal it is not the bacteria but the decomposing organic matte with which we are chiefly concerned. Such organic matter is compose of unstable molecules, imperfectly oxidized, which can be disposed of i two ways. First, it may decompose, putrefy, break down, with the production of offensive gases of decomposition, creating a nuisance, and i some cases, as in one or two heavily polluted rivers in Massachusetts actually endangering the health of adjacent communities. Or, secondly under the influence of oxygen it may undergo another process that w call nitrification, a slow burning or combustion which converts th organic matter into nitrates, or other mineral substances, without th production of foul odors and in a wholly satisfactory way. Organi matter must either putrefy or nitrify, and the aim of sewage treatmen is to nitrify it. This is a difficult problem, because it involves the suppl to that organic matter of one to three times its weight of oxygen, wit the special conditions under which the oxygen and the organic matte will unite.

Disposal by Dilution. — The most obvious way to dispose of sewag is to throw it into the nearest body of water. Before true sewers existe the natural drains discharged into the nearest water course, and whe they became filled with polluting matter the same plan was followed Sometimes this works very well. If the volume of sewage discharge into a stream is sufficiently small, there may be enough oxygen to unit with the organic matter and enough organic life in the stream to effec that union. Under such condition there results a self-purification o the stream of a very satisfactory type. The problem changes, however, when the volume of sewage exceeds the maximum which may b absorbed by a given stream, which may be stated as one part of sewage to fifty parts of water. When that limit is exceeded, when th limit of available oxygen for the oxidation of organic matter is passed then the conditions of putrefaction are set up. It is like Mr. Micawber' philosophy: "Annual income twenty pounds, annual expenditures nineteen-ought and six, result happiness. Annual income twenty pounds annual expenditures twenty pounds ought and six, result misery." Up to a certain point everything goes well, but beyond that point conditions are totally changed, and instead of a self-purifying stream you find a foul septic tank such as Boston has possessed for some time in front of her most costly residential street, in the Fens basin. Dilution then — the discharge of sewage into water — is limited by the volume of sewage in relation to the body of water into which it is to discharge. On the seacoast the conditions for purification by dilution are ideal; and with large rivers like the Mississippi this method may be followed very satisfactorily. In smaller streams we get the septic tank condition of which I have spoken. In Massachusetts alone there are at least seven rivers so polluted as to become a public nuisance for a part of their course. The Neponset at Hyde Park and the Blackstone River below Worcester will occur to all as conspicuous examples.

Disposal on Land. — A second obvious method of sewage disposal is discharge on the surface of the soil; and this method has been followed from time immemorial. In the little city of Bunzlau in Prussia there was a public water supply as early as 1559, piped from a spring, and in connection with it was installed a sewerage system and a system of disposal on a sewage farm. At this time it was thought that you could not only dispose of sewage satisfactorily by discharging it on land, but that a good deal of profit would come from the fertilizing effect of the material. So the practice of sewage farming spread, and in England, just after the period of sanitary reform in the early sixties, grew up very rapidly. A number of irrigation areas successfully operated today were laid out in England at that time. The largest and most famous examples of this process are the sewage farms at Paris and Berlin. In Berlin the flow of sewage from a population of 1,750,000 is treated on 23,000 acres of land at a rate of 3,000 gallons per acre per day. Crops are cultivated and the farm is operated with fair success, the operation being carried out by convicts under military discipline. The process of irrigation, or sewage farming, seems to work satisfactorily wherever there is available an ample area of suitable soil, but in many cases such large areas cannot be found. In many parts of England and in some places on the continent of Europe the process is impracticable because it is impossible to get sufficient land of the right kind.

There is a certain sanitary danger in the process of sewage farming if the crops grown are not properly regulated. A recent English com mission has recommended that no crops for human consumption grown on fields used for the disposal of sewage. That is an extrem conservative position; but certainly, I think, crops should be limited those food substances which are to be cooked before eating. T economy of the system of sewage farming is still more doubtful. is never good policy to recover something valuable which costs m to recover than it is worth after recovery. That appears frequently have occurred in the experience of those who have tried sewage far ing, since in many instances the expenses of conducting the farms really not paid by the crops grown on them. This does not hold go in arid regions where sewage is valuable, not only for its manurial e ments, but for the water it contains; in the far West we find that t sewage farm has a most important place. The city of Pasadena, example, has operated a sewage farm for twelve years. Alfalfa a crops of that character were grown at first with poor success, becau the crop being so near the ground, it was impossible to cultivate properly and keep the surface open. The city is now growing mai walnuts, with considerable profit. In 1903 the receipts from the fa were about eleven thousand dollars and the expenses about six th sand dollars, and out of the profits the original cost of buying the la is being paid off at a rapid rate. In a country of that sort the proces quite profitable, and no doubt sewage farming will have a large fut in the arid regions of the West. In the East, however, where th is plenty of water, the value of the process is extremely doubtful, if no other reason than because of the difficulty of securing economi administration under American municipal conditions.

Disposal by Intermittent Filtration. — The process of sewage pur cation on land soon underwent a development along more intens lines. As early as 1865 the German engineer, Mueller, urged t disposal of sewage through land at a more rapid rate than is possi on the ordinary sewage farm. He understood the nature of the pr ess, and knew that it was carried out by organic life; and in 1878 patented a system "for the disinfection, purification, and utilization sewage by the scientific cultivation of yeast-like organisms." His wo however, made no lasting impression. In 1870 the subject was proached along a different line by the English experts of the Riv Pollution Commission under the leadership of Frankland. These exp menters failed to grasp the biological character of the process, but th understood its chemistry and showed that sewage could be successfu purified by filtration through various soils, at much higher rates than those used on sewage farms. This principle, worked out by Frankland, was applied in practice as early as 1871 by Bailey-Denton at Merthyr-Tydfil in Wales, where a filtration area was so operated as to care for 60,000 gallons per acre per day for some years.

It was only by work in this state, however, that these various lines of investigation were brought together in so conclusive a form that the importance of the process of intermittent filtration through sand was generally understood. The difficulties experienced by Worcester through the pollution by its sewage of the Blackstone River and the proposition to treat the sewage of Boston and the cities lying to the north, on the Saugus marshes, made sewage disposal an urgent question in Massachusetts in the early eighties. As a result of these conditions the Lawrence Experiment Station of the State Board of Health was founded in 1887 for the study of the sewage purification problem. There, under the leadership of Mr. Hiram F. Mills, with the coöperation of Professor T. M. Drown and Professor W. T. Sedgwick, were carried out the series of experiments since rightly spoken of as classic. Ten circular cypress tanks 17 feet in diameter and 6 feet deep were filled with various filtering materials — sand, gravel, peat, river silt, loam, garden soil, and clay. The fine materials like peat, garden soil, and clay soon clogged, but the beds of sand worked to admiration, receiving sewage above and yielding a clear, bright spring water below. Some of the original tanks have been operated from the day of their installation to the present, a period of over seventeen years, with continuously good results.

The Massachusetts investigators established very clearly that the purification was an oxidizing process, carried out by bacteria living in the sand, and that a rich supply of oxygen was necessary for their activity. In order to supply the oxygen it was necessary to dose the filters intermittently, putting on perhaps one dose a day in an amount of some 60,000 gallons per acre. These experiments led at once to the installation of a number of intermittent sewage filters in Massachusetts, and in 1903 we had twenty-three in operation in different parts of the state, the best known being those at Marlboro, Brockton, Framingham, Gardner, and Clinton; some of them have been in operation now for over ten years. It has been found that a certain amount of solid material accumulates on the surface of such beds, but the material is of a stable nature, not subject to decay, and can be scraped off at intervals and removed at some expense for labor. Col winter weather interferes somewhat with the efficiency of the process but by ridging the beds so that the sewage may flow in furrows unde the ice, it is possible with most of the filters in Massachusetts to tre the sewage all the year round. Altogether, intermittent filtration ha proved a very satisfactory method of disposal in regions covered wit glacial drift, like New England, where large areas of coarse sand ar easily available. When, however, you come to a country like Ne Jersey, where the soil is largely clay, or to many districts in Englan where the soil is chalky or rocky and areas of sand are not to be foun intermittent filtration becomes almost impossible, because the cost o filters artifically constructed to operate at such low rates would b prohibitive.

The Septic Tank. — It was necessary in England to develop som new and more rapid method, and as a result three main processes hav come into use. The first of these, the septic tank, is designed as a pr lude to the ordinary nitrifying process. It is the logical developme of the cesspool and of the *fosses fixées*, used in France by Mouras a early as 1860. The principle — that the storing of sewage witho access of air led to a sort of fermentation, or ripening, which removed considerable portion of the solid material — was patented in 1882. Scot Moncrieff, an English engineer, in 1891 used the same process in wha he called a cultivation tank, and in 1894 one was installed at Urban Illinois, by Professor Talbot. The process did not attain wide popularit however, until after 1895, when Donald Cameron, of Exeter, Englan gave it the picturesque name of the septic tank. Cameron's relatio to the septic tank is much the same as that of the Massachusetts Stat Board of Health to the process of intermittent filtration through san As in the latter case, the principle of the liquefying tank was know before, but it was Cameron who showed the practical importance of th process. He first used a closed tank, but he soon found that this wa needless; it was only necessary to allow the liquid to flow slowly throug any tank, so as to have a storage of about twenty-four hours, the exa length of time varying with different sewages. Under such conditio decompositions take place, which remove from 60 to 70 per cent. of th suspended solids, turning a part into liquid form, giving off a part a gas, about $7\frac{1}{2}$ gallons of gas to 100 gallons of sewage, and storing certain amount of solids in the tank. The proportion of the soli destroyed in the tank — digested, so to speak — varies with differe sewages and with the same sewage, at different times, under conditions not thoroughly understood. It was claimed at first that all the solids settled out would be liquefied in the septic tank, but this is not true; a portion only disappears, and most tanks must be opened once or twice a year for the removal of sludge.

The Contact Bed. — Meanwhile progress was being made along a different line. The chemist of the London County Council, Mr. W. J. Dibdin, undertook in the early nineties to devise some more rapid method of sewage disposal than that worked out at Lawrence. He first tried experiments in Barking, at one of the outfalls of the London system, in which he passed sewage through coke and stone in iron cylinders. Finding the process fairly satisfactory, he laid out a one-acre bed filled with coke, made tight — so that he could fill it with sewage, allow it to stand for a certain period, and then empty it. This he called the contact system, because the sewage is held in contact with the coke by the closing of the outlet. In further experiments at Sutton in Surrey, Dibdin developed the double contact system, carrying the sewage treated in one contact bed to another contact bed and treating it again. By each contact about half the impurities in the applied liquid are removed. It has been found that in the construction of contact beds almost any hard, smooth material may be used, the bed being simply a tight box for holding it. Coal and coke are particularly favorable, though stone or almost any other hard substance may be used. The size of the pieces of material, whatever it may be, varies from $\frac{1}{8}$ of an inch to $1\frac{1}{2}$ inches. The beds are commonly made from 3 to 6 feet deep, or thereabouts, but the depth does not seem to be of great importance. The sewage is run slowly into the bed, allowed to stand for a certain time, generally two hours, and then discharged, three or four fillings being made in the twenty-four hours.

The effluent from a double contact system is of good quality, so that it will not decay and can be discharged into a river with safety. The worst difficulty with the method is that there is considerable stoppage or clogging of the beds, due to settling, due to breaking down of the material, due to the growth of organisms in the bed, and partly to the deposition of solid mineral matter in its interior. Stoppage due to breaking down may, of course, be controlled somewhat by using hard material. Stoppage due to the growth of organisms can be checked to a considerable extent by a proper resting of the beds. It apparently does not tend to go beyond a certain point. The loss of capacity or clogging due to the deposition of mineral matter is serious, and with many sewages appears to necessitate the rene the beds at intervals. After five years in some English plant instance, it has been found that the beds must all be dug ove refilled.

The process in the contact bed is a very complicated one, si involves the alternation of two conditions, the aërobic and the anaë During the full period the organic elements are absorbed by the l rial films on the stones, and during the empty period the principal of the purification goes on with free access of air. When the next of sewage enters the bed there is an entire reversal of conditions the setting up of anaërobic fermentations, and the success of the pr depends on a delicate balance between the two conditions.

The Trickling or Sprinkling Filter.—The third process devel in England was the process known as trickling filtration. In s of the early Lawrence experiments sewage was passed through ra coarse material, and air was forced in from below to check the and to supply oxygen for nitrification. Lowcock at Malvern in I land installed a plant on this plan in 1892, and in 1894 Colonel Wa carried out experiments with a similar process at Newport, having ta out a patent on it three years before. Theoretically, this seems t a satisfactory process for combining the necessary elements—sew bacteria, and oxygen—but it is almost impossible in practice to su sufficient oxygen To insure success it would be necessary to su from three to five times as much air as there is sewage purified.

The filtration of sewage through coarse material under continuo aërobic conditions was finally worked out, not by forced aëration, by sprinkling the sewage over the whole surface of the filter be a continuous fine spray, so that the oxygen went in along with it, sewage never filling the tank but continuously trickling through the tering material. A filter of this type made of broken chalk was built by Stoddart in 1893 and exhibited by him at Bristol in Engl Meanwhile Corbett, of Salford, had worked out a similar idea; Sc Moncrieff, Ducat, and others contributed to the development of type of purification. One of the advantages of the trickling bed sys is the extreme simplicity of its construction. It is only necessar have a heap of material over which the sewage can trickle. It ne of course, some kind of floor sloped to carry off the drainage, but a from that the material used can be held together by wooden pali or iron bands, or any very simple structure around the outside. The depth is generally 4 feet or over, and, as in the case of the contact bed, any hard material may be used, varying in size from $\frac{1}{8}$ inch to $1\frac{1}{2}$ inches.

The most serious difficulty is in regard to the distribution of the sewage. It must be so applied as to pass through slowly and well mixed with air. Colonel Ducat used tipping buckets, a series of triangular troughs which discharged at intervals, splashing little dashes of sewage over the surface. Stoddart used a trough, from which the sewage overflowed continuously, dripping off from numerous points below; this was good in theory, but difficult to keep working in practice, because the troughs buckle and any difference in level prevents an even distribution. At Salford they used sprays with fixed pipes, like a series of fountains, and many of the English plants are equipped with complicated revolving mechanisms like lawn sprinklers. The most cumbrous of all these contrivances is a radial carrier which moves round and round the bed, its extremity revolving on the wall at the periphery, — dripping sewage as it goes. The rates which may be obtained by the trickling process are very high. The sewage farm will take perhaps an extreme of 10,000 gallons, the intermittent sand filter perhaps 100,000 gallons, and the contact bed 500,000 or 600,000 gallons per acre per day; the trickling filter, on the other hand, easily treats 2,000,000 gallons per acre per day, giving an effluent on the whole better than the contact bed, though not so good as the sand filter. It contains a considerable amount of suspended solids, and does not look as clear as the effluent from the contact bed. But the effluent analyzes well and keeps well, which are the principal points to be considered. Furthermore, its solids may be easily removed by a short period of sedimentation.

Progress in England. — The early English results on what are called the biological methods — although the intermittent filter is a biological method, the name has been particularly applied to the contact and trickling systems — led first to the construction of contact beds. At Exeter, for example, the double contact system was installed. At London it was recommended that the sewage should be treated in septic tanks and single contact beds, although the plant has not yet been begun. At Manchester, experiments in 1899 led to the recommendation of septic tanks, with double contact beds; and forty-eight acres of first contact filters are already in operation. The second contact beds have not yet been built, and the work of the primary filters has not been altogether what was hoped. The next important experiments were carried out another great manufacturing centre, Leeds, and there the contact s tem received a setback. It was found that the beds clogged so bad with so great a loss of capacity, that the cost of renewal would be p hibitive. By the use of the trickling filter, however, the sewage cou be well purified, and the installation of trickling filters has been planne though not yet executed. At Birmingham the problem was next tacked, and the experts came to the conclusion that the trickling filt is best adapted to local conditions; construction has already been begu At the present time, while the sewage farm exists in a number English cities, no new ones are likely to be laid out and the old on will be gradually abandoned, in all probability. The tendency now toward the installation of septic tanks and trickling filters. The tid may change again in a few years more, but at present these are th popular systems in English practice.

European Practice. — In Germany progress in sewage treatment ha been very slow, much slower than in England. The problem has no pressed so hard, the population being less dense and the rivers larger It has been possible, as a rule, where sewer systems exist to discharg the sewage directly into streams. Some admirable work has indee been carried out at the Hamburg Testing Station, under Dr. Dunbar, particularly with relation to the theory of the action of the contact bed; and within the last four years a testing station has been founded in Berlin which has yielded important results. As yet the septic tank has not found favor in Germany — whether on account of carelessness in operation, or on account of the large amount of industrial waste materials in the sewage, is not quite clear. In the use of the contact system it has been found necessary to renew the beds quite often, even once or twice a year, a necessity which the German engineers appear to regard with equanimity. The trickling filter is just beginning to be known, and at Berlin is awakening some enthusiasm. Progress in Germany has only followed that in England; and on the rest of the continent practically nothing has been done except in the line of sewage farming. French engineers have recently visited England and carried home news of the biological experiments; but that is practically all.

Conditions in the United States. — In the United States the problem is a diverse one. As in the case of water purification, local conditions in different parts of the country must be met by totally different methods. Here in Massachusetts the intermittent filter is perfectly satisfactory, and probably will be used for a long time to come. West of the Alleghanies it is often impossible to install such filters, because the required areas of sand are not available. In the Middle West we generally find the septic tank combined with the sand filter, because it is thus possible to treat the sewage at higher rates. Contact beds and one or two interesting trickling filters have been installed in these regions. The question of sewage purification in the Middle West will largely be controlled by the results of the experiments just completed at Columbus. Columbus is the first American city — the Lawrence Station being, of course, a state institution — to approach the subject of sewage purification in a rational way. It bids fair to be the model sanitary city of the country, with unique and interesting systems of sewage disposal and water purification, and probably a fine garbage disposal plant as well. About a year ago the city called in Messrs. Hering and Fuller to investigate and report on the best method of sewage treatment, and appropriated nearly fifty thousand dollars for experimental work. A fine experiment station was equipped, in which studies were made of over forty separate methods of disposal. The experts have finally reached the conclusion that the best treatment for Columbus sewage is by the use of the septic tank, followed by the trickling filter and this again by sedimentation; and they are now proceeding with the construction of what will be the largest plant in the country, including ten acres of trickling filters. This will surely lead to the construction of numerous similar plants in regions where conditions are similar to those at Columbus.

Experiments at the Technology Experiment Station.—At the Sewage Experiment Station connected with the Massachusetts Institute of Technology experiments on the treatment of Boston sewage were begun a year before those at Columbus, but we are prepared at present to make only a preliminary report. We found, in the first place, that the sewage of the South Metropolitan District is a fairly strong city sewage — a sewage from a city sewered on the combined system, which receives street washings as well as household waste — peculiar only in that it contains a somewhat large amount of suspended matter and considerable sea water, which backs up through leaking tide gates. The first problem which always confronts the engineer in the disposal of sewage is the question of the removal of solids, and it is necessary to distinguish between two or three kinds of solids. In the first place, there are large floating objects, such as rags, bits of wood, etc., which must always be removed by screening. In the next place, we find rather coarse min matter, gravel, etc., from street washings. This will settle out q readily if, for example, the flow be checked to half a foot per sec for a very few minutes. Material of this sort, which we call detri must always be removed in any system. It is almost entirely inorga of such a nature, therefore, as not to require purification. We h spread the detritus removed at our Albany Street Station during whole period of experimentation, in the yard of the station with causing a nuisance. When, however, you consider the more fin divided matter, organic in nature, which will settle out only if y reduce the flow to one-tenth of a foot per second for several hou the difficulty becomes more serious. This finely divided suspended m ter may be removed in several ways. The old method for its remo was to treat the sewage with chemical precipitants, but the chemic are costly and increase the amount of sludge to be handled; only exceptional cases is that method now used. In such cities as Worcest where the sewage contains large amounts of certain industrial was materials, which hinder the biological process and favor the chemic process, precipitation is useful; but from a general consideration of t problem chemical treatment may be dismissed. There are, then, besid the use of chemical precipitants three alternatives with regard to t organic suspended matter. You may either leave it in the sewage be treated afterward in the contact or trickling filter or sand bed, you may take it out by plain sedimentation or by the septic tank. T difference between plain sedimentation and the septic tank is simp that in the septic tank the flow is continuous; the tank is not emptie and the accumulation that settles out is maintained in contact with t material that flows over it. The removal of the sludge is due alwa to sedimentation. In the septic tank you store the sludge after remo ing it, and allow the bacteria to liquefy a part. That might seem clear gain in the use of the septic tank as compared with plain se mentation; and the septic process certainly disposes of a certain p tion of the sludge by liquefaction, the amount varying with the speci sewage treated. Furthermore, the actual removal of solids from t effluent is probably greater, from the liquefaction of particles too fi to settle out. The idea that a favorable action on soluble matter exerted in the septic tank which makes the later nitrifying proce easier is very doubtful. There is no evidence of any favorable actio there is, on the other hand, evidence that the septic process m exercise an unfavorable action on the sewage, producing poisonous substances which interfere with proper oxidation. At Andover in this state it has been found more difficult to treat sewage which has been septicized than crude sewage. In our own experiments we have found that sewage which has been septicized is much more difficult to handle than crude sewage. This appears to be largely due in our case to the presence of calcium sulphate from the sea water, which decomposes in the septic tanks and forms harmful compounds of sulphur. Such a condition must occur, not only in marine cities, but in some inland cities where there are hard waters. We are not quite prepared to say that the septic tank cannot be used in some form with Boston sewage. It may be possible by limiting the action to a brief period, or by subsequent aëration, to avoid hampering the nitrifying bacteria. Along those lines we are still experimenting.

The third alternative to septic treatment or sedimentation is to put the sewage directly on the nitrifying beds, whether contact, sand, or trickling filters. The tendency in England is almost entirely against any such action. They think there that the septic treatment or very thorough sedimentation is absolutely necessary, and, indeed, with many sewages it is. Personally, I do not believe it is safe to say that it is necessary with all sewages. There is no doubt that if you do not do it you will get sludge in your sand bed, contact bed, or trickling filter, and that will sometimes necessitate the renewal of filtering material. Also, there is no doubt that sludge is much harder to remove from the contact or trickling bed than from the septic tank. But, on the other hand, there is some evidence that the sludge is very much less in amount in the contact or trickling bed than in the septic tank, because the oxidizing processes going on in the tank consume a large proportion. The difficulty of sludge removal from the contact bed or trickling filter must be balanced against the cost of the installation and operation of the septic tank or sedimentation basin. Only experimentation in each particular case will determine what method is most desirable for the sewage in hand.

Disposal of Boston Sewage. — With regard to final purifying processes, we have found in our experiments that crude Boston sewage can be treated in sand filter beds at quite a high rate, at the rate of 400,000 gallons per acre per day. That rate, of course, is higher than could be attained in practice, because in our small experimental tanks we can get the sewage distributed very evenly over the surface of the beds, and be-

cause they are protected from the severity of winter. We are anxio
however, that the attempt should be made with filters in actual ope
tion to use higher rates than are now common on sand filter beds. V
are inclined to think that the sand filter has never been pushed qu
as hard as it might be. Of course, with higher rates you get mo
sludge on the surface, which will mean more costly operation. But
is a question whether it will cost much more to get 200,000 gallo
through one acre than to get 200,000 gallons through two acres. Wi
double contact beds we have found it possible to treat Boston sewa
at a combined rate on two beds of 700,000 gallons per acre per da
Clogging occurs, which would probably render renewal of the first co
tact beds necessary at intervals of three or four years. Either of the
methods would prove extremely costly for so large a city as Boston.

In regard to trickling beds, our experiments have not yet bee
carried far enough to get definite results. With that particular proce
it is necessary to work on a large scale and out of doors; so during th
past summer we have constructed an out-of-door trickling filter, whic
will take 10,000 gallons of sewage in the twenty-four hours at the rat
of 2,000,000 gallons per acre per day. The English results have shown
as I have already said, that the trickling filter can treat sewage at muc
higher rates than other processes, giving a very satisfactory effluent, an
that the body of the beds is cheaper to construct. On the other hand
the difficulties are two — the distribution of the sewage and the possib
bad effect on the beds of the severe winter climate in this country. Th
question of distribution is a very serious one. In Columbus they us
a system of buried pipes, with sprinkler heads at intervals to spray th
sewage over the beds. In our filter the sewage drops from a woode
trough into metal cups, and splashes from them over the bed. This
we think, is simpler than any other device in use, and we hope will no
be as seriously affected as some others by the climate. At presen
engineers need to develop a cheap and practical system of distributio
and need more light as to the effect of a severe winter climate on tric
ling beds with various types of distributers. If those two problems ca
be solved it seems that the trickling filter furnishes the best treatmen
of sewage known. If it is necessary to produce the very highest purific
tion, the turbid effluent from this type of bed may be settled and steri
ized by copper or some other process, or may be strained rapidly throug
sand. In that way it is perfectly easy to make a bright, clear effluen
at no very high cost. The trickling bed appears to be the ideal metho

for solving the essential problem of sewage disposal, the oxidation of organic matter. It exhibits the simplicity of all scientific applications, which are merely intelligent intensifications of natural processes. A pile of stones on which bacterial growth may gather and a regulated supply of sewage are the only desiderata. We meet the conditions resulting from an abnormal aggregation of human life in the city by setting up a second city of microbes. The dangerous organic waste material produced in the city of human habitations is carried out to the city of microbes on their hills of rock, and we rely on them to turn it over into a harmless mineral form.

EXPERIMENTS ON THE PURIFICATION OF BOSTON SEWAGE, 1903-1905

By C.-E. A. WINSLOW and EARLE B. PHELPS,
OF BOSTON, MASS.

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INTRODUCTORY.

The Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology was established by a friend of the Institute for the purpose of making experiments and promulgating information with regard to the scientific disposal of sewage, especially the sewage of large cities.

The laboratory and station are situated in the southeasterly part of the city of Boston, near the corner of Massachusetts Avenue and Albany Street. Connection is made by a two and one-half inch iron pipe and suction hose with the nine-foot sewer of the Boston main drainage system at a point on Massachusetts Avenue, about 200 feet below the entrance of the Albany Street intercepting sewer. Prior to October 14, 1904, sewage from the whole of Boston south of the Charles, with the exception of the Dorchester and South Boston districts, together with sewage collected by the South Metropolitan sewerage system, from Waltham, Newton, Watertown, Brighton and Brookline flowed past the station intake. In 1903-04 the flow at the station was above fifty million gallons a day from a district with a contributing population of 350,000, sewered for the most part on the combined system.

The sewage, drawn from the sewer by a 4 by 6 duplex Warren power pump, passes through a grit chamber made of an iron casting 16 inches deep and 19 inches in diameter, with a central screen having one-half inch openings. Here the velocity of the sewage is checked to .04 feet per second for about 45 seconds. The sand and other detritus taken from this chamber amounted in sixteen months to 4,800 pounds of wet material or .65 cubic yards per million gallons of sewage. Analysis indicated that the 4,800 pounds of detritus contained 1,300 pounds of water, and only 319 pounds of organic matter. As a whole the material was of an innocuous character, and during the whole course of our experiments it was spread out on the land adjoining the station without producing any nuisance.

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* Preliminary Abstract.

THE CRUDE SEWAGE.

The average yearly results of almost daily analyses of the crude sewage as it reached the station after passage through the grit chamber are given in Table I.

TABLE I.

COMPOSITION OF BOSTON SEWAGE.

Parts per million.

No. of Samples.	Date.	Turbidity.	Temperature.	Nitrogen as						2 minutes boiling. Oxygen Consumed.		Oxygen dissolved.
				Alb. Ammonia.			Free Ammonia.	Nitrites.	Nitrates.			
				Total.	Solution.	Suspension.				Total.	Soluble.	
102	June '03–June '04.	.....	60	6.33	3.11	3.22	19.7	0.27	0.06	45.2	22.5	2.8
159	June '04–June '05.	305	58	5.67	2.96	2.71	17.6	0.14	0.12	41.5	24.6	2.2

The organic constituents of the Boston sewage are quite normal in their relation to one another. Regular determinations of the organic nitrogen were not made, but judging from the average of some fifty such determinations made at various times in the course of experimental work, it may be stated that the organic nitrogen figures for the whole period average about 20 parts per million. In this respect the sewage appears to be about the same strength as the average sewage of Massachusetts cities, being slightly weaker than the sewages of Lawrence and Gardner (new system), and somewhat stronger than the sewages of Framingham, Worcester and Brockton.

The inorganic analysis of mixed weekly samples which covered the calendar year 1904 showed 2,300 parts per million of chlorine, 15 parts of iron, 125 parts of alkalinity as calcium carbonate and 220 parts of SO_3 as sulphates.

The high chlorine and suphate values are due to the large amount of sea water present in the sewage of Boston. Assuming the chlorine, normal to the sewage itself, to be equal to the total nitrogen, a simple calculation shows that the amount of chlorine present represents a volume of sea water equal to 11 per cent. of the total volume of the sewage. This, however, is only an average value for the period.

During each twelve hours the chlorine reaches a maximum figure o from 3,000 to 4,000 parts per million, representing 19 per cent. of se water, while between these maxima there are minimum points o about 200 parts per million representing only one per cent. of se water. It may be an important question in any project for the purification of Boston's sewage whether the extra cost of pumping an treating this amount of sea water might not be greater than the cost o keeping it out of the sewers. In this connection it might also be wel to consider the possibility that a large amount of sea water, saturated as it is with oxygen, may be of actual advantage in any aerobi process of treatment.

The suspended solids, amounting to some 300 parts per million, ar considerably higher than the average for American sewages.

THE SEPTIC TANK.

Assuming that if any preliminary treatment were necessary i the purification of Boston sewage, the septic tank would probably furnish the most available method, the next problem was to determin the best conditions under which a septic tank could be operated. I particular we desired to compare the efficiency of different periods o storage, the results obtained from open and closed tanks and the effec of filling a tank with stone in order to increase the amount of surface action.

Our experiments were carried out in six cypress tanks, each 6′ 4′ x 3′ deep. Tanks 7 and 9 were open. Tanks 5, 6, 8 and 10 wer closed in with tight planking, Tank 6 was filled with 1½″ crushe stone. The rate and the average analysis for each effluent are show in Table II.

TABLE II.

ANALYSIS OF CRUDE SEWAGE AND SEPTIC EFFLUENTS.

General Averages.

(Parts in 1,000,000.)

	Date.	Storage Period. (Hours.)	Turbidity.	Temperature.	Nitrogen as				Oxygen Consumed. 2 minutes boiling.	
					Alb. Ammonia.			Free Ammonia.		
					Total.	Solution.	Suspension.		Total.	Soluble.
Sewage	June 1903–June 1905.		305	59	5.94	3.02	2.92	18.5	43.1	24.4
Sewage	Mar. 1904–June 1905.		305	58	5.66	2.97	2.65	17.6	41.5	24.7
Tank 5	June 1903–June 1905.	48–12*	200	57	3.80	2.64	1.16	20.7	36.9	26.9
Tank 6	June 1903–June 1905.	24	175	57	3.41	2.52	0.89	21.5	37.8	26.0
Tank 7	Mar. 1904–June 1905.	12	170	55	3.37	2.50	0.87	17.6	33.2	27.9
Tank 8	June 1903–June 1905.	48	190	57	3.84	2.58	1.26	22.1	40.7	29.9
Tank 9	Mar. 1904–June 1905.	24	170	55	3.24	2.43	0.81	19.4	34.1	27.5
Tk. 10	June 1903–June 1905.	24	210	56	3.77	2.53	1.24	22.5	37.5	24.5

* Changed December 7, 1903 from 48 hours to 12 hours.

Septic action began in all the tanks very soon after they were started, the effluent being free from gross turbidity and much darkened. The dark color and offensive odor of the septic effluents are undoubtedly due in part to the formation of sulphides from the sulphates introduced in the sea water. Scum formed at first on the open tanks, but later disintegrated and sank without reforming. In the closed tanks a scum an inch thick was found when they were finally opened.

Inspection of Table II shows that the septic tanks reduced the total albuminoid ammonia to from two-thirds to one-half its sewage value. The diminution of dissolved albuminoid ammonia was slight but distinct, while the suspended portion was reduced to a little over one-third its original amount. Comparison of the different effluents shows a remarkable uniformity of results. In comparing tanks 5 and 10 (closed) with the corresponding 12 and 24 hour open tanks, the open-tank effluents appear to be slightly better. It must be remembered, however, that the open tanks were operated during the last fifteen month only, when the sewage was weaker. Taking this factor into accoun the work of the open and closed tanks is practically equal.

With regard to period the figures are no more conclusive. Comparing tanks 7 and 9 (open), there appears to be no important difference between the effect of 12 and of 24-hours' storage. Similarly tanks 5, 8 and 10 (closed) produce almost the same results, althoug operating with periods varying from 12 to 48 hours. The length of th storage period seems therefore not to be a matter of great importanc Tank 6, with 1½" crushed stone, produced a somewhat greater reduction in suspended albuminoid ammonia than did the other tanks; bu the difference is too slight to be of great practical importance.

When this series of experiments was closed in June, 1905, the inle and outlet of each tank were closed and the contents, including scum and sludge, thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the materia which had accumulated during the whole period of operation. From the results we have calculated, in Table III, the actual amounts of certain constituents which were (*a*) allowed to enter the tanks, (*b*) discharged in the effluents, (*c*) stored in the tanks as sludge and scum and (*d*) removed by septic decomposition. About 50 pounds of nitrogen as albuminoid ammonia per million gallons of sewage entered th tanks; 30 pounds, roughly, were discharged and 20 pounds remaine behind, of which from 15 to 17 pounds were decomposed. The las columns in the table show the total volatile solids and fats stored i the various tanks calculated in relation to the sewage treated. Thes figures bring out very sharply the superior decomposing power of th tanks operated at short periods. Tank 7 (12 hours) and tank 5 (1 hours for the last eighteen months) show the lowest values. Tank 9 and 10 (24-hour period) come next, with 90 and 101 pounds respectively. Tank 8, with its 48-hour period, stored 206 pounds of organi matter per million gallons of sewage treated. The large proportion o fats indicated in the last column is notable, amounting as it does to one fourth or one-eighth of the total stored organic matter.

Altogether we may conclude from our experiments that the septi tank will effect a considerable removal of solids from Boston sewag amounting to some two-fifths of the nitrogen as measured by albuminoid ammonia. Its effluent is free from gross turbidity, but dar and offensive from the liberation of hydrogen sulphide. Of th organic matter retained in the tank a very large proportion, amountin to well over three-fourths if measured by the albuminoid nitrogen, i decomposed and the accumulation of stored material in the tank is slight after two years of operation. Apparently such tanks might operate for several years without being cleaned. The covering of tanks is immaterial since closed and open tanks work equally well. Storage periods, varying from 12 to 48 hours, give similar effluents, but there is an increasing tendency to accumulate sludge as the period is lenghtened. This, may probably be due to the accumulation of harmful bacterial products which check the liquefying organisms. The filling of a septic tank with stone is of only slight advantage.

TABLE III.

STORAGE AND DECOMPOSITION OF ORGANIC MATTER IN SEPTIC TANKS.

(Pounds per million gallons.)

	Flow. (Gallons.)	Storage Period. (Hours.)	Nitrogen as Albuminoid Ammonia.				Solids Loss on Ignition Stored.	Fats Stored.
			Entering.	Leaving.	Stored.	Decomposed.		
Tank 5	445,000	48-12*	49.2	31.7	1.3	16.9	69.0	16.2
Tank 6	135,000	24	49.2	28.3	10.1	11.9	......	101.
Tank 7	393,000	12	46.7	28.3	.4	18.1	35.3	6.3
Tank 8	133,000	48	49.2	31.7	2.6	15.9	206.	29.3
Tank 9	197,000	24	46.7	26.7	1.5	17.8	89.7	25.0
Tank 10	266,000	24	49.2	31.7	1.6	17.3	101.	15.3

* Changed December 7, 1903, from 48 hours to 12 hours.

THE INTERMITTENT SAND FILTER.

The sand filters studied were cypress tanks, 6′ x 4′ x 3′ deep. Over 6″ of underdrain material, graded from 3″ stones down, was a layer of drift sand of an effective size of .14 mm. and a uniformity coefficient of 3.5. The sand in tank 2 was one foot deep and in tanks 1, 24 and 25, two feet deep. Tanks 1 and 2 were dosed with crude sewage, tank 24 with 12-hour septic effluent, and tank 25 with 24-hour septic effluent. The rate on tanks 1 and 2 was at first .1 million gallons per acre per day, but on tank 1 it was gradually worked up to .4 million gallons per acre per day, the daily dose being divided into four portions, applied at six hours' intervals.

These experiments gave quite conclusive results as to the minimum depth for a sand filter. Tank 2, with its one foot of depth, proved a complete failure. Its effluent was dark and turbid, and offensive in odor. Not one of the samples tested passed the incubator test. The analytical results showed marked variations from time to time, but the free ammonia present was generally from 15 to 20 parts per million, nearly as high as the crude sewage. The albuminoid ammonia was usually between 2 and 3 parts, and the oxygen consumed in the neighborhood of 20 parts, in each case about half the sewage value. Nitrates were always low.

The operation of the other beds, on the contrary, was eminently satisfactory. All three effluents were clear and bright, entirely free from turbidity and odor and stable by the incubator test. The average analyses in Table IV show that the effluent from the treatment of crude sewage was slightly better than that produced by the treatment of septic effluent. The increase in rate on tank 1 from .1 to .2 and again from .2 to .4 did not appreciably alter the quality of its effluent.

TABLE IV.

ANALYSIS OF SAND FILTER EFFLUENTS.

(Parts per million.)

Tank.	Receiving.	Nitrogen as				Oxygen Consumed. 2 min. boiling.	Oxygen dissolved.
		Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.		
1	Crude sewage	4.2	.6	.4	22.3	5.6	6.1
24	12-hour septic effluent	5.0	.8	.3	19.9	6.5	7.5
25	24-hour septic effluent	5.6	.9	.2	16.0	6.5	7.2

The surface of the filters, even at such high rates, did not require undue care. Tank 1 was scraped in August, 1903, and November, 1904, and raked once and scraped once in March, 1905. The total material removed in three scrapings during two years of operation, amounted to a layer .48 inches in thickness or 1,600 cubic inches. The filters taking septic effluents showed still more favorable results During their fifteen months of operation tank 24 was raked over twice and scraped once, while tank 25 was raked over once and never scraped.

In general our results indicate that in reducing the depth of a sand filter it is not safe to go below 2′. A single foot of sand is insufficient to produce purification, while a two-foot bed may yield admirable results. With regard to the value of preliminary septic treatment of Boston sewage before sand filtration, it appears that effluents from the combined process are slightly inferior to those obtained by the sand process alone, while the care of the surface is more difficult when crude sewage is treated. We believe our experiments indicate that it may be possible to treat crude sewage by sand filtration at higher rates than have heretofore been recommended. We are aware that the operation of filter beds under practical conditions is much more difficult than in such experiments as ours, on account of imperfect distribution and the detrimental effect of severe weather conditions. Yet we believe that our results suggest the possibility of operating sand filters, with proper care and the application of several doses of sewage during the twenty-four hours, at higher rates than those commonly in use.

THE CONTACT BED.

The experiments on contact treatment were made in cypress tanks four feet square, four being four feet deep and five, six feet deep. Of the six foot single-contact beds, two were filled with ½″ broken stone, one with 1″ broken stone, one with 1½″ broken stone and one with 2″ coke. During the second year the one-inch tank was emptied and refilled with facing bricks, laid in even tiers after the pattern of Dibdin's multiple-surface bacteria bed. The four-foot double contact beds were so arranged as to give two primary beds of 1½″ stone, and two secondary beds of ½″ stone. One pair took crude sewage and the other pair septic effluent, which had received thirty hours' treatment.

In each case the mode of operation was as follows: the bed was filled during the course of an hour, allowed a two-hours' contact period, emptied in about half an hour and allowed to stand empty till the next filling. All the beds were started with one filling a day. In August, 1903, the rate on four of the single contact beds was increased to two fillings and that on the fifth to three fillings a day. The higher rate seemed to give better results so in January, 1904, the rate on the four beds was again increased to four fillings. This proved somewhat too strenuous, however, and since June, 1904, all the beds, single and double alike, have received three fillings in the twenty-four hours.

Capacity measurements were made on each bed once a week by discharging the effluent into a measuring tank. The initial liquid capacity varied from 39 per cent. to 48 per cent., the highest values, of course, being found in the brick and coke beds. The single contact beds taking crude sewage all decreased in capacity quite steadily, reaching a final value, after two years, of 26-33 per cent. The Dibdin brick filter still showed 40 per cent. open space after one year of operation. The first contact bed receiving septic effluent, and both second contact beds, maintained capacities of over 35 per cent. The loss of capacity was made good to some extent by resting.

The average analyses of the effluents from the various beds are brought together in Table V.

TABLE V.

GENERAL AVERAGE. ANALYSES OF CONTACT FILTER EFFLUENTS.

(Parts in 1,000,000.)

Filter.	Date.	Material.	Size of Material	Average Rate.	Turbidity.	Temperature.	Nitrogen as						Oxygen Consumed. 2 minutes boiling.		Oxygen dissolved.	Capacity.	
							Alb. Ammonia.			Free Ammonia.	Nitrites.	Nitrates.					
							Total.	Solution.	Suspension.				Total.	Soluble.		Initial.	Final.
Tank 11	June '03–June '05.	Coke	2 "	1.8	130	57	3.16	2.17	0.99	18.9	.45	1.08	22.1	15.5	0.50	46	32
Tank 12	June '03–June '05.	Stone	1½"	1.4	130	57	3.15	2.12	1.03	17.6	.52	1.34	25.3	16.3	0.40	40	30
Tank 13	June '03–June '05.	Stone	½"	1.2	55	56	1.96	1.45	0.51	11.0	.69	7.22	14.3	9.8	1.37	44	33
Tank 14	June' 03–June '04.	Stone	1 "	1.4	155	57	3.56	2.43	1.13	20.0	.49	0.04	28.3	14.0	0.36	42	...
Tank 14A	June '04–June '05.	Brick	......	2.0	195	57	3.89	2.38	1.51	16.4	.23	0.38	27.5	20.4	1.42	48	40
Tank 16	June '03–June '05.	Stone	½"	1.2	65	58	1.73	1.34	0.39	8.1	.83	9.80	13.1	9.6	1.28	42	30
Tank 17*	June '03–June '05.	Stone	½"	1.2	80	55	2.26	1.70	0.56	15.5	.35	5.20	16.9	11.7	0.55	39	35
Tank 18*	June '03–June '05.	Stone	½"	1.1	80	57	2.11	1.49	0.62	11.5	.67	8.60	16.1	12.4	1.25	42	37
Tank 19†	June '03–June '05.	Stone	1½"	1.2	155	56	3.33	2.28	1.05	20.9	.21	0.91	28.0	19.0	0.38	41	38
Tank 20	June '03–June '05.	Stone	1½"	1.1	120	57	3.64	2.48	1.16	15.4	.50	4.01	22.4	15.4	0.84	41	26

* Second contact beds. † Receiving septic effluent.

With regard to kind of material, a comparison of tank 11 (2″ coke) with tank 12 (1½″ stone) shows that the effluent of the former was slightly better than the latter, in spite of the larger size of the material and the higher rate.

On the more important question of the size of material, a comparison of tank 12 (1½″ stone), tank 13 (½″ stone) and tank 14 (1″ stone) is instructive. The effluents from the 1″ and 1½″ stone were never of satisfactory quality except, in the latter case, at the very end of the experiment, while that from the ½″ stone was generally clear and non-putrescible. The result in this case was only reached, however, at the expense of a serious clogging which necessitated the removal of four inches of sludge from the surface during two years of operation, leaving the body of the filter for some way below the surface still badly clogged. These results correspond with those obtained by Dunbar and other German investigators. They show that with beds of fine material a good effluent may be obtained by a single contact, but at the cost of such clogging as to necessitate somewhat frequent removal of the upper portion of the bed.

Data bearing on the effect of contact beds of different depths may be obtained by comparison of tanks 12 and 20. Both were filled with 1½-inch stone and dosed with three fillings a day of crude sewage. The depth was six feet for tank 12 and four feet for tank 20. It is apparent that the results of treatment in the four-foot bed are consistently better than in the six-foot bed. In particular it will be noticed that the nitrification is more complete in the shallow filter; but the difference is scarcely great enough to compensate for the diminished rate.

A comparison of the double contact systems, 17 and 19, and 18 and 20, furnishes interesting results with respect to the value of preliminary treatment. The primary beds were both 4′ tanks filled with 1½″ stone. It will be noticed that the effluent of tank 20, which took crude sewage, was markedly superior to that of tank 19, dosed with septic effluent, except, for part of the time, in its albuminoid ammonia content. The effluent from tank 20 was often non-putrescible while that from tank 19 was always foul and offensive. As pointed out above, the septic treatment was efficient in preventing clogging, the final capacities of tanks 19 and 20 being 34.6 per cent. and 26.5 per cent., respectively. This advantage is, however, dearly bought, since the septic effluents from Boston sewage evidently contain substances inimical to bacterial action which seriously interfere with subsequent purification. Even the secondary filter effluents showed the same deleterious effects. In nitrogenous constituents and in available oxygen, the effluent of tank 18 was better than that of tank 17. The former was clean and stable, the latter generally dark colored and smelling of hydrogen sulphide.

In general it appears that a single contact treatment will remove from one-third to one-half of the organic constituents of sewage with the production of an improved but still putrescible effluent. Beds of ½" stone form an exception to this rule, since after a time they may yield a stable effluent, but at the cost of very serious surface clogging.

Secondary contact treatment effects a removal of one-third to one-half of the remaining organic matter, producing a satisfactory effluent in the case of the treatment of crude sewage. Preliminary septic treatment for thirty hours, although it maintains the capacity of the beds, exerts a detrimental effect in the treatment of Boston sewage, producing an effluent hard to purify even by the double contact system. The possibilities of septic treatment before contact filtration can not be considered as exhausted, since we have only tried rather old septic sewage (30 hours), without any special method of aeration.

CONCLUSIONS.

It will be necessary in any treatment of Boston sewage to screen out large floating bodies and to settle out mineral detritus. In our judgment, this process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to some 1,600 pounds per million gallons of sewage, and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected if desired by treatment in the septic tank. An open tank operates just as well as a closed one, and there is no marked advantage in filling the tank with stone. .Varying the storage period from 12 to 48 hours produces no difference in the effluents which is measurable by analytical results. All our tanks removed nearly two-thirds of the suspended albuminoid nitrogen and produced an effluent fairly free from suspended matter, but much darkened by hydrogen sulphide. The tanks on an average received 50 pounds of nitrogen as albuminoid ammonia (dissolved and suspended) of which 30 pounds were discharged in the effluent, 15-17 pounds were decomposed and 3-5 pounds were stored as sludge. In the decomposition of sludge, the length of the septic period is of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed, is twice as great with a 48-hour period as with a 24-hour period and four times as great as with a 12-hour period.

Under the conditions of our experiments, crude Boston sewage has been successfully filtered through a two-foot bed of sand, with an effective size of .14 mm., at a rate of .4 million gallons per acre per day, divided into four doses in the twenty-four hours. We should not expect such high rates in actual practice, but we do believe that with care in construction and operation the sand filter may be efficient at higher rates than has been generally recognized. The effluents obtained from our sand beds were clear and bright and well purified. The depth of the beds can not safely be reduced below 2 feet. Preliminary septic treatment for 12 or 24 hours does not improve the effluents obtained with sand filtration, although it makes the care of the surface of the beds somewhat easier.

Crude Boston sewage may be treated in single contact beds of fine stone (one-half inch diameter) at a rate of about 1.2 million gallons per acre per day. The effluent is only partially purified, although generally so stable as to be discharged into water without any tendency to create a nuisance. The beds clog rapidly and the surface needs much attention. The double contact system of treatment in primary beds of 2″ material and secondary beds of ½″ material would yield a fairly well purified and stable effluent at a rate on the combined double system of about .7 million gallons per acre per day with beds 6′ deep. Such a system clogs somewhat, and would require resting and renewal at frequent intervals. Preliminary septic treatment for thirty hours enables the beds to maintain a higher capacity but produces an effluent which, without special aeration, is so difficult to purify that their efficiency is seriously interfered with. The most practical method of those which we have studied would appear to be the treatment of sewage, either sedimented or subjected to a very short period of septic action in double contact beds. The process of trickling filtration remains to be considered in a further report.

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THE INTERPRETATION OF A SEWAGE ANALYSIS

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IT is often the case that analytical data express to the mind of t analyst the direct information desired, but at times there are cases which such figures convey no useful information until they are examin in the light of past experience. For example, in an assay of a gold o the results require no explanation, but the results of a steel analy convey to the lay mind only the idea that there were present in t steel certain very small amounts of sulphur, carbon, phosphorus, et To the expert, however, these figures of the steel analysis stand clear and definitely for certain marked properties in the steel.

This expression of analytical data in terms of physical or oth properties of the substances analyzed is called an interpretation of analysis.

In the case of sewage there are, unfortunately, no well-mark physical characteristics such as are found in steel with which o analytical data may be compared. The interpretation of a sewa analysis is largely a matter of experience on the part of the analy or of reference to other analyses for the sake of comparison, rath than any concrete reference to definite properties. Nevertheless wh sewages are spoken of as "strong domestic," or "typical city," it doubtful if any analyst could, from these descriptions, satisfactori reconstruct the essential features of the original analyses.

In view of the fact that important steps are being taken just n toward standardizing and unifying our methods of analysis, it h seemed to the writer that a brief discussion of our present knowled of the chemistry of sewage, so far as it relates to the routine analyti procedure, might not be out of place. To attempt to place the interpretation of a sewage analysis upon the same plane as that of a steel analysis would, of course, be out of the question. It would seem, however, that we have already at hand sufficient analytical data to warrant us in an attempt at correlating this material with the more important variable characteristics of the sewage. It will be necessary first to define these characteristics, keeping in mind the fact that they must be, first, variable and correlated with the analytical data, and, second, of sufficient importance in the ultimate problem of sewage treatment to warrant their study.

These characteristics in a sewage are three in number: the physical property of concentration; the chemical property of composition; and the biological property, which I will call condition.

First in importance is the concentration of the sewage, or, more accurately, of the dissolved and suspended matters in the sewage. By this factor one does not mean merely the concentration as determined by the total solids. For a thorough understanding of the processes of sewage purification the concentration of the organic nitrogen, organic carbon, fats and fatty bodies, and, to a lesser degree, of the various mineral constituents should be known.

Hardly second in importance is the chemical characteristic or composition of the sewage. Here I would eliminate the idea of mere concentration and confine the thought to the actual composition of the solid material. A thorough study of the composition of a sewage would necessarily include complete determinations of the various organic and inorganic substances present. While such analyses would doubtless be of considerable value in enabling us to understand the reactions involved in purification, yet it is doubtful if our increased knowledge would be at all commensurate with the time and labor involved. By a suitable comparison of the concentration values previously mentioned, however, it may be possible to distinguish between certain types of sewage, such as purely domestic sewage, street washings, and factory and other industrial wastes, and, in the case of a sewage of a mixed and variable type, to describe somewhat roughly its actual composition. Obviously this is a matter requiring careful study in attempting any new purification work.

As a first type for such comparison we may study a number of purely domestic sewages. Such sewages will differ widely in the matter of concentration, but in the relative amounts of nitrogen, carbon, and chlorine they might all be expected to agree within fairly clos limits. Variation in these relative numbers would then in any give case denote a variation from the domestic type.

Let us take as an example an actual case. The ratio between th total nitrogen and the chlorine in domestic sewages, as will be show later, is approximately unity. But at certain times this ratio, in th case of the Boston sewage, may reach as low a figure as one to on hundred, from the backing up of sea water through leaking tide gates Now if it may be assumed that the normal chlorine value of th sewage in Boston is also equal to the nitrogen, then with the know composition of sea water a simple calculation will show the amoun of sea water in the Boston sewage. It is not intended that in ordinary cases the analyst shall attempt in this way to calculate th actual amount of street washings, or other material which has entere the sewage in question, but it is believed that by the use of thes composition factors sewages may be classified and compared with eac other as to the probable effect upon them of purification treatment

The third important characteristic of a sewage I have called it condition. By the condition of a sewage I would denote what w variously call its age, freshness, or septicity. But condition as her used is a much more definite property than this, and cannot be expressed as a function of the time alone. Condition is a product of a least three prime factors and of many other minor ones. The thre most important are age, temperature, and the number and character o organisms present. Among the other factors may be mentioned th degree of physical disintegration, opportunity for aëration, the presence of germicidal substances, and doubtless many unknown condition It will thus become apparent that the mere statement of the age o a sewage, as of a septic sewage, for example, will throw very little ligh upon its true condition. In attempting to establish condition factor we shall deal not alone with the unvarying constituents, such as th total nitrogen and the total carbon, but with the various forms in whic the nitrogen, for example, may occur, and their transformations fro one to the other through the activities of the microörganisms or b spontaneous chemical action.

Having now defined the three characteristic properties of a sewag in terms of which we shall attempt to interpret our analytical data, le us examine in some detail our ordinary analytical procedure and se what significance the results have in terms of these properties.

NITROGEN

Nitrogen is determined in four forms, namely, as organic nitrogen, ammoniacal nitrogen, and the nitrogen of nitrous and nitric acids The two latter forms, containing oxygen, are chiefly significant for that reason, and will be discussed under the head of oxygen.

The Organic Nitrogen.—This constituent as determined by the Kjeldahl process is the most valuable of the concentration factors. Nitrogenous organic matter is, *par excellence*, the substance in sewage requiring purification. Its accurate determination is therefore of first importance in a sewage analysis. In addition to its use as a concentration factor the organic nitrogen figure may be usefully combined with other figures to express ratios showing condition and composition.

The Albuminoid Ammonia.—On the question of the value of the albuminoid ammonia figure as an additional aid in fixing the condition of a sewage little need be said. Clark (1904) has published what is perhaps the most thorough study yet made of this question. By averaging a large number of results from similar samples, and from these averages calculating the ratios of the albuminoid ammonia to the organic nitrogen, he obtained somewhat different ratios for the different conditions of the sewage. The individual deviations from these average ratios in any one group are, however, so great as to entirely mask any significance which these ratios may have. The fact that distinctive ratios can be brought out by averaging would seem to indicate that such figures, if accurately determined, might have considerable value, but that the inaccuracies inherent in the Wanklyn process are sufficient to make the individual determination of little value. Obviously the albuminoid ammonia has no value as a concentration factor.

Free Ammonia.—The nitrogen occurring in the form of ammonium hydrate or of ammonium salts is called "nitrogen as free ammonia." The determination, as usually carried out by distillation from alkaline solution, gives results on sewage which are considerably in excess of the true value as thus defined. This excess is due to the breaking down of unstable nitrogenous material. The German procedure of direct nesslerization, after clarification of the sewage, yields results which are much nearer the truth. There is indeed a slight loss due to adsorption of the ammonia by the precipitate, but by proper manipulation this loss may be reduced to a negligible quantity. Since most of our present data have been obtained by the distillation method, the discussion which follows will consider only such results, although the writer is convinced that much more constant and significant ratios could be obtained fr the figures if they had been obtained by the direct method.

In a very fresh domestic sewage the ratio of the ammonia nitrogen to the organic nitrogen is usually about one to two. T applies only to sewage from a small sewer running swiftly. In larger intercepting sewers of our cities this ratio will be, as a rule, v close to unity. At the other extreme, an old septic sewage in wa weather may show a ratio as high as seven to one. In calculating ratio in this case allowance must be made for the fact that sedimer tion is taking place. The organic nitrogen value to be used in ratio is not the actual value found, but should be calculated on assumption that the total nitrogen — organic plus ammoniacal — has undergone any diminution during the treatment, an assumption si ciently exact for this purpose. This total nitrogen value, then, sho be taken from the unsedimented sewage. Between these two extrer will be found the ratios for ordinary sewages. The rate of change d not seem to be proportional to the time. The ordinary staling o sewage is not accompanied by a marked rise in the ratio, while in later stages of active purification a rapid increase is noted.

This ratio is obviously a factor changing with the age of the sewa The rate of such a change will be affected by the temperature of sewage, and will also depend upon the number and nature of organis present. In a septic tank, for example, the change will take place mı more rapidly than during the movement of the sewage through the sew

No further experimental proof of the fact of the increase of t ratio with age is needed, for it is a matter of common knowledge. an illustration of the application of this factor in actual practice, following analyses of Boston sewage at different seasons are giv This sewage is for the major part less than an hour old. The analy show the effect upon this condition factor of varying temperature, ot things being practically constant.

TABLE I.—Showing the Effect of the Temperature upon the Ratio o the Ammoniacal to the Total Nitrogen

Month.	Average temperature.	Number of determinations.	Ratio of Ammoniacal to Organic Nitro		
			Mean.	Maximum.	Minimun
July	71	8	1.70	3.35	1.44
September . .	65	8	1.08	1.38	0.79
January	47	10	0.82	1.22	0.47

The value of some such a condition factor in discussing and comparing septic sewages will be readily apparent. The usual method of describing such sewages by age only obviously omits the other important factor — temperature — not to mention possible differences in the number and kinds of bacteria originally present. In describing sewages which have not been subjected to septic treatment, not much has hitherto been attempted. Such terms as fresh and stale sewage have been used without any very sharp definitions. The application of condition factors such as have been described and of which other examples will be given will, it is believed, greatly facilitate our descriptions and even clear our conceptions of these matters.

A New Nitrogen Factor. — The application of the nitrogen analytical data to the question of composition as used in this paper still remains to be worked out. Our data so far do not give us any information as to the ease or difficulty of purifying our nitrogenous matter nor of the stability or non-stability of the nitrogenous matter in an effluent; in other words, we know nothing of the *kind* of nitrogenous matter we are dealing with. In the writer's view these two things are identical, that is, a stable effluent would be difficult, and an unstable one easy of further purification. Furthermore, it is believed that the ability of the nitrogenous matter to hydrolyze is a measure of its non-stability or of its ease of purification. Upon this principle the writer is working out the details of a new nitrogen factor which shall be the desired composition factor. Such a factor is of special value in the analysis of effluents, and, it is hoped, may be fully discussed in the second part of this paper, which will deal more especially with the question of effluents.

CARBON

Our knowledge of the carbon in sewage through our analytical results is meagre indeed. The oxygen-consumed test is a measure of the carbonaceous matter present; unfortunately it is also a measure of the nitrites, ferrous salts, part of the chlorine, and doubtless of many other substances at present unknown to us. Add to this the fact that almost every laboratory has its own method of making the determination, and two things become apparent: first, that the results of the different laboratories are not at all comparable, and, second, that the best of the results have but little real value in the interpretation of an analysis. The arguments which have been used for the accurate determination of the total nitrogen apply with hardly less force question of total carbon. The oxygen consumed stands in the relation to the total carbon as the albuminoid ammonia to the nitrogen. But the present conditions are much more unsatisfact the former case; for the amount of carbon represented is only 3 per cent. of the total carbon, while the albuminoid ammonia one-third or more of the organic nitrogen. What is true of the va ratio existing between the albuminoid ammonia and the total nit is doubtless equally true as between the oxygen consumed and the carbon. Hence the oxygen-consumed figures have no value as co tration factors, and, while they may be combined with the total gen figures to form composition ratios, the results are only rough are not independent of the condition, as composition factors shoul For example, the ratio of the total carbon to the total nitrogen w be an ideal composition factor, since the condition of the sewage w have but slight influence upon it; but the ratio of the oxygen sumed to the total nitrogen will vary with the condition, and henc not a satisfactory composition factor. It is possible, however, to this rough factor to distinguish between purely domestic sewage the one hand and on the other the same sewage mixed with a siderable volume of street washings or of factory wastes from suc process as tanning. Taking the oxygen-consumed figures as determi by the Kubel hot-acid method, with two minutes' boiling we find i domestic sewage which is reasonably fresh that the oxygen-consu values are roughly about 50 per cent. greater than the total nitro values. Immediately after a heavy shower this value will increase three or four times the nitrogen figure. The fact must be emphasi however, that by mere aging of the sewage the same change in ratio may be brought about.

Since we have but one carbon figure in our analysis, no condi factor based upon carbon alone has been yet developed, although comparison of values obtained with and without heating seems pro ing. The change suggested above, while an important correction the composition factor, is too variable and untrustworthy in its na to be of any service in denoting condition from the carbon standpo

OXYGEN

In any ultimate study of processes of sewage purification, either from the point of view of chemical energetics or of biological metabolism, the oxygen of the organic matter must needs be taken into account. Our present state of knowledge, however, does not warrant any such difficult determination as that of the oxygen of the organic substances, and in the present discussion that oxygen will be left entirely out of consideration. There remain, then, the oxygen which is dissolved in the sewage and that which is present in the form of mineral salts, notably as nitrites and as nitrates. Obviously the oxygen thus present has no relation to the concentration of the sewage, and its incidental and brief occurrence can be of no service in fixing the composition. Oxygen is then of importance only as a condition factor. Its importance in this rôle is so great that its determination becomes one of the most important in our scheme of analysis. In the discussion of the free ammonia-organic nitrogen ratio as a condition factor, it was stated that the increase in this ratio proceeded slowly at first. It is true that even in warm weather sewage may be as old as fifteen hours with but slight indication of the fact from this ratio. When putrefaction once sets in the ammonia ratio is important, but up to that time we must rely entirely upon the oxygen values. Fortunately these are easily determined, and are thoroughly indicative of the condition in the earlier stages. The free dissolved oxygen and the nitrites and nitrates probably enter the sewage with the domestic water, although in cold weather the production of nitrates undoubtedly takes place in the sewage. From that time forward, except under very peculiar circumstances, the tendency is towards the redistribution of this oxygen by the bacteria and their products. The rate of change of the oxygen is therefore a measure of the activity of those bacterial processes which are taking place within the sewage, and which by definition are altering its condition.

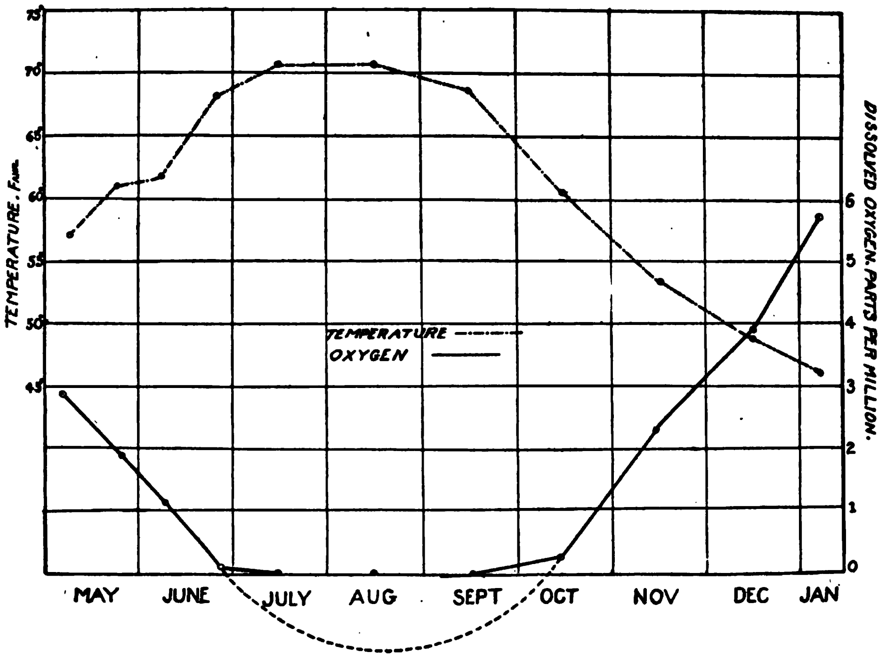
There is some reason to believe that by interaction between the nitrites and certain decomposition products of the sewage, still ultimately due to the bacteria, a certain amount of the nitrites are consumed by direct chemical reaction. Under such extremely anaërobic conditions as are found in the septic tank, other salts, such as the sulphates and phosphates, are likewise reduced. So sensitive is this oxygen test for condition that in the case of the Boston sewage collected at the Sewage Experiment Station, a place at which the majority of the sewage arrives when less than an hour old, the amount of the dissolved oxygen is a seasonal function. It is entirely absent during the three summer months, begins to appear in the early fall, and reaches a maximum value sometime in midwinter, decreasing again as the warmer weather arrives.

In Table II are given these results, together with the temperatures for nine months. The figures given are monthly or semimonthly averages of almost daily determinations. During May and June the changes were so rapid that semimonthly periods were chosen instead of the monthly periods used during the remainder of the year.

TABLE II

Month.	Average temperature, F.	Average amount of dissolved oxygen. Parts per million.
May 1 to 16	57	2.9
May 17 to 31	61	1.9
June 1 to 15	62	1.1
June 16 to 30 . . .	68	0.1
July	71	0.0
August	71	0.0
September	68	0.0
October	61	0.3
November	53	2.2
December	49	3.9
January 1 to 15 . . .	46	5.7

In the accompanying diagram these figures are given in graphical form. From the manner in which the oxygen line approaches the axis, the dotted portion of the line, lying below the axis, is suggested. This would, of course, mean a negative value for the dissolved oxygen. In reality we may have some such a condition as this, although it is not truly a negative dissolved oxygen. After the dissolved oxygen of the sewage is entirely used up, the microörganisms begin to draw upon other substances containing oxygen. Sulphates, phosphates, and ferric



CURVES SHOWING RELATION OF TEMPERATURE TO DISSOLVED OXYGEN IN BOSTON SEWAGE

salts are reduced, giving rise to products which will readily become oxidized again upon exposure to oxygen. If such an extremely anaërobic sewage be mixed with equal portions of water containing, let us say, ten parts per million of dissolved oxygen, and the dissolved oxygen of the mixture determined immediately, the amount found will be small or altogether wanting. It is this ultra-anaërobic condition of a sewage which I have represented by the dotted line, although its existence in this case is purely hypothetical. Its determination by the method indicated is entirely feasible, and the actual condition of a sewage containing no dissolved oxygen can only be expressed in terms of this negative quantity which I would call "*oxygen avidity*."

The order of disappearance of the three forms of oxygen, namely, the free dissolved oxygen and that of the nitrates and the nitrites, seems to vary with the other variable conditions. Nitrates are found in the fresh Boston sewage most commonly in midwinter, and the nitrites generally have their maximum at that time, but there is no such direct seasonal effect noticeable as there is with the free oxygen. In some laboratory experiments made to determine, if possible, the order of disappearance of the three forms, the effect of temperature and of the organisms present was strikingly shown. These experiments were carried out as follows: A sample of fresh sewage was collected directly from the manhole of the sewer. With this three bottles were filled. To each bottle was then added a small amount of paraffin oil to keep the sewage out of contact with the air. Dissolved oxygen samples were then taken from each bottle by means of a siphon. Samples were also taken for nitrates and nitrites. Bottle No. 1 was kept at a temperature of about 10° C., and bottles Nos. 2 and 3 at about 22° C. To bottle No. 3 a small amount of sludge from a septic tank was added in order to seed it with the septic tank organisms. The changes in the amount of dissolved oxygen, nitrates, and nitrites were then studied by determining these substances at intervals. The results of the series are shown in Table III.

TABLE III

EXPERIMENT I. RAW SEWAGE. TEMPERATURE, 10°

Time.	Parts per Million of Oxygen as		
	Free, dissolved.	Nitrates.	Nitrites.
1/13–10 A.M.	5.8	2.7	3.8
1/13–2 P.M.	5.0	3.0	3.8
1/13–5 P.M.	1.0	10.7	0.8
1/14–10 A.M.	0.0	0.0	0.0
EXPERIMENT II. RAW SEWAGE. TEMPERATURE, 22°			
1/13–10 A.M.	5.7	2.7	3.8
1/13–2 P.M.	2.0	0.0	0.0
1/13–5 P.M.	0.5	0.0	0.0
EXPERIMENT III. RAW SEWAGE SEEDED WITH SEPTIC. TEMPERATURE, 22°			
1/13–10 A.M.	5.5	2.5	3.4
1/13–12 M.	0.0	0.0	1.7
1/13–2 P.M.	0.0	0.0	0.0

Apparently under various conditions of temperature the relative changes in these three substances may be in one or another direction, and these changes are influenced by the bacteria. While it is perfectly feasible to define the several conditions of a sewage in terms of these three oxygen factors, and, if necessary, to determine, as in the experiments cited, the direction of the changes taking place, yet we are not able, with our present knowledge, to apply these condition factors to the practical problems of sewage treatment. That there is a considerable seasonal difference in the results of sewage purification is well known. In ordinary out-of-door work this difference is in favor of the summer season for reasons which are manifest. By eliminating as far as possible the effect of temperature upon the filter itself, which is possible only with small, indoor filters, these seasonal differences are reversed, the fresher winter sewage, with its plentiful supply of oxygen, being much more readily purified. This general observation is about all that we can make at this time. How much of this effect is due to the mere presence of the oxygen in preserving the activity of the filter, how much to the preponderance of bacterial nitrification over bacterial reduction (as shown in Experiment I), and how much to the absence of putrefactive changes which are themselves induced largely by the lack of oxygen, are questions to be answered by future investigations, and they are questions which must be fairly met and answered before we may claim to have a thorough knowledge of the purification processes with which we are dealing.

One word may be said in favor of the practical use of the condition factors here suggested. Results obtained empirically on any one sewage will be made available for general use only after we have discovered what are the important characteristics of sewage in relation to its treatment. Concentration and, to a large extent, composition characteristics are directly comparable. If these condition factors are found to be essential ones in determining the results of sewage treatment, then we may reasonably hope in the near future to be able to make use of the large amount of empirical data which today has little value except in reference to the sewage on which it was obtained.

CHLORINE

It would seem from wholly *à priori* reasoning that the relation of the chlorine to the total nitrogen in sewages from various localities would be a fairly constant quantity, these two elements being both of fundamental character in food. Such, indeed, is the case in the majority of instances, although an occasional striking exception seems to lessen the value of the ratio in fixing the composition of a sewage. Unfortunately the data available for determining this ratio with exactness are very meagre. Clark (1904) gives the results of total nitrogen determinations on the sewages of sixteen cities and towns of Massachusetts. Five or six determinations were made on each sewage; the albuminoid ammonia determinations were made at the same time. From this series of results the writer has calculated the average ratio between the albuminoid ammonia and the organic nitrogen for each locality. In another place in the same report are given yearly averages of monthly analyses of these same sewages, but without organic nitrogen determinations. Applying the ratio previously found to the albuminoid ammonia figures given in these averages, it has been possible to estimate with fair accuracy the amount of organic nitrogen, and from this to establish the desired chlorine-nitrogen ratio. Table IV contains the results obtained in this way. Some results obtained by Fuller (1894) from four of these localities and one other, as well as the results from three English cities obtained by Rideal (1904), are also given.

The sewages from these cities and towns show, with a few exceptions, a fairly constant chlorine-nitrogen ratio of from one to one and a half. Three of the sewages are strikingly peculiar — Concord, Lawrence, and Natick. In Concord a large amount of ground water finds its way into the sewers, as is indicated by the extreme dilution of the nitrogenous material. There can be little doubt that a large part of this water is purified sewage with a high chlorine value. In Lawrence the very abnormal chlorine value may be due to mill liquor. Both Natick and Leicester have dilute sewages whose high chlorine ratios may be due to chlorine in the diluting ground water. The fact that a fairly constant ratio can be obtained in the case of most localities makes it seem very probable that the exceptions represent real variations from the normal domestic type.

TABLE IV.—SHOWING THE RATIO OF THE CHLORINE TO THE TOTAL NITROGEN IN SEWAGES FROM VARIOUS SOURCES

(Parts per million)

Place.	NITROGEN AS			Chlorine.	Cl ÷ N
	Free ammonia.	Total organic (calc.).	Total.		
Andover	39.7	16.8	56.5	70.0	1.2
Clinton	33.3	23.7	57.0	59.5	1.0
Concord	5.7	4.2	9.9	26.6	2.7
Framingham	26.1	16.3	42.4	69.9	1.6
Gardner (old)	20.2	14.8	35.0	33.8	1.0
Gardner (new)	27.3	19.8	47.1	43.8	0.9
Hopedale	18.3	8.5	26.8	22.3	0.8
Lawrence	18.1	23.4	41.5	120.1	2.9
Leicester	22.0	8.3	30.3	54.7	1.8
Marlborough	25.9	14.8	40.7	59.0	1.4
Natick	12.2	7.9	20.1	59.5	2.9
Pittsfield	12.0	20.4	32.4	25.7	0.8
Southbridge	16.1	8.9	25.0	29.0	1.2
Spencer	14.9	11.4	26.3	39.9	1.5
Stockbridge	9.8	3.3	13.1	12.8	1.0
Westborough	13.8	11.1	24.9	23.7	1.0
Framingham	22.0	14.9	36.9	27.0	0.7
Gardner	8.8	9.6	18.4	29.0	1.6
Lawrence	10.8	14.5	25.3	37.5	1.5
Marlborough	27.1	20.4	47.5	45.0	0.9
Worcester Hospital	6.1	32.0	38.1	32.5	0.9
Exeter, England	. .	. .	63.7	75.0	1.2
Sutton, England	. .	. .	88.1	89.9	1.0
London, England	. .	. .	70.6	104.0	1.5

FATS AND FATTY BODIES

The determination of the fats and soaps in sewage is one v importance is generally overlooked. These bodies are undoub responsible for much of the clogging properties of a sewage whic noticed particularly in sand filtration. The fats, being non-mis with water, are the less readily decomposed, a feature which is mented by the very stable nature of the bodies themselves. ((1904) gives as the average yearly amount of these bodies, fats soaps combined, in the Lawrence sewage about six parts per hun thousand, or 20 per cent. of the total combustible solids. In the t ment of the sewage of large private country residences great diffic is found in properly dealing with the fats, which in this case am to a very much larger percentage of the total solids. In one such which has recently come under the writer's study the sewage contai 2,100 parts per million of volatile solids, of which 1,400 parts per mil or 66 per cent., were fats. In our interpretation the fats have a v as concentration factors only. Their determination is of consider importance for the sake of comparisons, and should be made regul in any systematic study. An occasional determination of the sepa substances, free fats, and soluble and insoluble soaps, would also ad our knowledge of the character of the sewage. This separation is ea made by the use of suitable solvents.

IRON, SULPHUR, AND PHOSPHORUS

The determination of these elements is not, as a rule, made routine work. It would be extremely useful, however, to establish normal amounts of these elements present in domestic sewages f various localities. Such data would be of value in calculating amount of added industrial waste or other liquor which contained tl elements. During the past year the writer has collected during e week an average sample of Boston sewage composed of equal port of each daily sample. On this sample the iron and sulphates l been determined. The sulphates in this case are influenced by presence of sea water and are, therefore, of no significance here. iron-nitrogen ratio is found to be 0.2 for the yearly average. Variat in this ratio are slight.

TURBIDITY, SEDIMENT, AND SOLIDS. LOSS ON IGNITION

The turbidity, if determined by a properly standardized method, is a rough measure of the suspended solid matter. The sediment is the amount of this matter which has settled out after a given period. The total solids are usually determined on the filtered as well as the unfiltered sample. The difference between these two determinations gives the amount of solid matter in suspension, that is, the turbidity. Probably the most accurate optical method of estimating turbidity is by some such instrument as the Jackson turbidimeter.[1] This instrument is calibrated against finely divided silica, and its readings on turbid waters are in close agreement with the actual gravimetric values found for the solids in suspension. It is unfortunately true that an optical instrument of this nature gives correct values only when the suspended matter to be determined is of the same size as that matter against which the instrument was calibrated. In reading sewage turbidities in terms of silica there is a greater and greater variation between the turbidities and the actual solids in suspension as the size of the suspended particles increases. Clark (1904, *a*) has recently proposed as a standard for sewage turbidities, and especially for the fairly coarse suspended matter in certain filter effluents, a suspension containing a known amount of this same coarse and at the same time fairly stable material. From this standards may be made up containing varying amounts of the suspended solids. By using such a material to recalibrate the Jackson turbidimeter, one should be able to read the solids in suspension in a sample of sewage with a very fair degree of accuracy. If the suspended solids are determined in this way there seems to be little need for the total solids determination. Its results are at best open to suspicion, owing to the difficulty of completely drying a sample without loss of organic matter. This is especially true in the presence of deliquescent salts.

The sediment may be determined by a second reading of the turbidity after the sample has stood for a standard length of time.

The loss on ignition shows in a rough way the amount of the total solids which are volatile at a low red heat. It therefore includes the organic matter, with the exception of some of the carbon which may remain behind as alkaline carbonate. It also includes all such volatile substances as ammonium carbonate and chloride, and to a sligh other mineral salts. The determination has never been regarded of much value.

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[1] TECHNOLOGY QUARTERLY, 1901, XIV, pp. 285–294.

ALKALINITY

Domestic sewage is normally slightly alkaline. The alkalin a sewage has little significance in the interpretation unless it h abnormal value. Such a characteristic might indicate the presen industrial wastes which would otherwise have escaped notice.

BACTERIA

The determination of the number of bacteria present in the sew gives us in general little if any additional knowledge as to its cha teristics. In certain special cases their total absence or presence comparatively small numbers might direct the attention of the anal to the presence of germicidal bodies in the sewage which would ha otherwise escaped detection. In the discussion of the question effluents the determination of the number and kinds of bacteria w be shown to have considerable significance.

UNFILTERED AND FILTERED SAMPLES

It is the usual custom in this country to make the principal determinations both upon the unfiltered sample and upon a sample which has been passed through filter paper. The differences noted are assumed to represent the amount of the substance in question which has been removed by filtration, and hence roughly the amount in suspension. In the determination of the total nitrogen or total carbon, such an assumption is legitimate. In using such comparative processes as the albuminoid ammonia and the oxygen-consumed processes, however, an error of considerable magnitude is thereby introduced. For example, the writer found in an extended comparison of the albuminoid ammonia with the organic nitrogen that as an average of a number of determinations 40 per cent. of the dissolved nitrogen and only 25 per cent. of the suspended nitrogen were recovered as albuminoid ammonia. In such a case the albuminoid ammonia might show equal amounts of nitrogen dissolved and suspended, when actually nearly two-thirds of the total would be in suspension.

In Germany and among certain English analysts samples are always filtered through paper before analysis. Such analyses are then published as analyses of the sewage. In defense of this practice it is said that an analysis of the sewage itself and not of the suspended solids is what is desired. Further comment is unnecessary except to state that such analyses are in no way comparable with our own.

CONCLUSION

In conclusion it may be well to bring together the various important analytical figures and factors which have been discussed in the preceding pages.

For concentration factors we should have determinations of the total nitrogen, total carbon, chlorine, and fats and soaps. Of minor importance, but useful in a systematic study for comparison, are the determinations of the sulphates, phosphates, and iron.

For composition factors the ratio of chlorine to nitrogen is perhaps under the present conditions of our analytical methods the best that we have. With the determination of the total carbon, the carbon-nitrogen ratio ought to prove of even greater value. The ratio of oxygen consumed to total nitrogen is only rough at best and is not independent of condition. It will, however, indicate any considerable change in the character of a given sewage, such a change as would be caused, for example, by a heavy summer shower.

For condition factors we have at present two independent sets of numbers. The oxygen values as found in the dissolved oxygen, nitrates, and nitrites serve as an admirable index of the condition of a sewage before putrefaction becomes active. During the later stages the free ammonia-organic nitrogen ratio is of great significance. The ratio of carbon oxidized by permanganate to total carbon may be found to have some value in determining condition. As a first prerequisite, however, a method must be developed for the oxygen consumed determination which can lay some claim to accuracy and constancy. In the accompanying sewage analysis there are given in ordinary type the analytical data which the writer believes will be found essential to a satisfactory interpretation of the analysis. The determinations in italics are not regarded as essential, but are of value in a systematic study of various sewages. New determinations will undoubtedly be added, such as, for instance, one which will show the tendency of the nitrogenous matter to hydrolyze (putrefy); possibly some new ratios will be found to denote condition, but in the main the analysis here given is an example of what ought to be done in sewage analysis. No argument based upon the time consumed in making such an analysis should have weight against the adoption of this procedure. The tendency should be towards average samples taken from the whole day's run of sewage or the whole discharge of an effluent. A thorough knowledge of the action of various germicidal bodies in preserving such samples is desirable. Certain determinations will doubtless have to be made immediately, but the majority of the determinations here recommended can be made on an average sample of one whole week if necessary. Fewer but more representative samples examined thoroughly will take no more time than the rough analysis of many samples.

The writer would emphasize the statement already made that the object of these proposed factors is not to enable the analyst to say that any given sewage is of a certain age or of a certain composition. Such information might be more readily and accurately gathered from a survey of the sewerage system, and in fact no such concrete reference can be made from the analysis. It is known, however, that a study of our filtration results, and especially those obtained at our experimental plants, leads us at present only to empirical data which are correlated but slightly with one another or with the results from other plants. It seems more than probable that such a condition is due to lack of proper interpretation of our analyses, and that if we can truly interpret these analyses in terms of essential characteristics from the point of view of purification, and study our purification results on the basis of this interpretation, then we shall find that these results are correlated with the analyses and with one another, and that it may be more possible than heretofore to predict the probable effect of treating a given sewage by a given system of purification.

In the present paper we have considered only the subject of raw or untreated sewages and of septic sewages. The analysis of the effluent of a sewage filter is made for the distinct purpose of estimating the efficiency of the process of purification, and the interpretation of such an analysis requires a treatment quite distinct from that given here to sewage analyses. In a future paper the writer hopes to take up the discussion of this other important phase of the interpretation of sewage analysis.

TABLE V.—SPECIMEN SEWAGE ANALYSIS

	PARTS PER MILLION.		
	Total.	**Dissolved.**	**Suspended.**
NITROGEN:			
Total	55.6	40.6	15.0
Organic	30.0	15.0	15.0
As NH_3	25.0	. .	. .
As N_2O_3	0.1	. .	. .
As N_2O_5	0.5	. .	. .
CARBON:			
Total	280.0	120.0	160.0
By $KMnO_4$	14.0	8.0	6.0
As CO_2	5.0	. .	. .
CHLORINE	60.0	. .	. .
OXYGEN:			
Dissolved	10.0	. .	. .
FATTY ACIDS:			
Total	61.0	30.0	31.0
Saponified	35.0	30.0	5.0
Unsaponified	26.0	. .	26.0
Sulphur	7.0	. .	. .
Phosphorus	1.0	. .	. .
Iron	12.0	. .	. .
Alkalinity	212.0	. .	. .
TURBIDITY:			
Total	320.0	. .	. .
On standing	260.0	. .	. .
Sediment (diff.)	60.0	. .	. .

RATIOS:	
Carbon-nitrogen	5.1
Chlorine-nitrogen	1.1
Ammoniacal-organic nitrogen	0.83
Carbon by $KMnO_4$*-total carbon*	0.05

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CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

II

THE INTERPRETATION OF AN ANALYSIS OF THE EFFLUENT FROM A SEWAGE FILTER

BY EARLE B. PHELPS

(Received April 3, 1905)

IN a previous paper the writer (1905) has described certain characteristics of a sewage, in terms of which the analytical figures may be interpreted, in order that sewages may be described and classified with reference to purification. The subject of sewage filter effluents, requiring, as it does, a distinctly different manner of treatment, was not considered at that time. The proper interpretation of the analyses of such effluents, however, is equally important in experimental work, and is the essential point in the work of the practical sewage filter. In the present paper it is the intention to discuss this phase of the sewage purification problem. Septic sewage was considered in the previous paper as a sewage to be purified. It must also be considered here, but as a partially purified effluent.

The subject of the quality of the effluents derived from a sewage filter has been considered from two totally different points of view, which have led frequently to conflicting opinions as to the results obtained. One view is based upon the actual work of the filter expressed in percentage efficiency, and necessarily takes into account the nature of the raw sewage. The other is based upon the quality of the effluent as shown by the analysis.

The former is, as a rule, the point of view of the investigator who is comparing the work of several types of filters upon the same sewage, and who finds in the percentage efficiencies of the several filters a convenient basis for such comparisons. The latter is the broader view of the sanitarian and of the public health official, whose duty it is to inquire, not what is the percentage removal of organic matter, but what will be the probable effect upon the health and comfort of the communities below of the discharge of this effluent into a stream. Both viewpoints must be taken, each supplementing the other.

The expression, "percentage removal," sometimes called the efficiency of the filter, is of very little value in the comparison of systems which are not receiving the same sewage, for it is much easier to get a high efficiency, calculated in this way, on a strong sewage than on one which is weaker. The figure in any case is of real value only when it is based upon determinations which are themselves total and not partial determinations. For example, it is obvious that the total organic nitrogen or total organic carbon of the raw sewage and of the effluent may be directly compared; but the comparison of such partial values as those of the albuminoid ammonia or of the oxygen consumed will give only misleading results. Whatever value such determinations may have in the comparison of like substances is entirely lost when the substances are unlike. The removal of bacteria may properly be expressed in the form of efficiency, but in the case of very good effluents this form of expressing results fails in another respect, in that a very short range of numerical efficiencies covers a wide range of actual conditions. For example, it might not readily be noted that in a given filter a change from 99.9 per cent. to 99.8 per cent. in the bacterial efficiency would mean a doubling of the bacteria in the effluent, while smaller but significant changes in the effluent would not appear in the efficiency number. On the whole it would seem that a better interpretation of the analysis of an effluent can be made than this customary comparison with the raw sewage. A direct comparison of effluents derived from the same sewage will serve the purposes of the investigator fully as well as a comparison of the efficiencies, while the quality of the effluent is the final and practical criterion upon which the work of the filter must be judged.

HISTORICAL. STANDARDS OF PURITY

In an act of the English Parliament of 1861, entitled "Local Government Act Amendment Act" (Great Britain, 1861), a provision prohibits the construction of new sewer outfalls which shall discharge any "sewage or filthy water into any natural water course or stream until such sewage or filthy or refuse water be freed from all excrementitious or other foul or noxious matter such as would affect or deteriorate the purity and quality of the water in such stream or water course." This act is of interest in that it is the first law, in England at least, requiring treatment of sewage. At that time no standards were available, and it would be of interest to learn just how it was determined when all such "excrementitious and foul matter" had been removed.

As early as 1872 (Great Britain, 1872), the first Rivers' Pollution Commission of England recommended the following standards of purity for effluents. A nonpolluting liquid shall not contain in 100,000 parts over three parts of mineral matter or over one part of organic matter in suspension; nor in solution shall it contain over two parts of organic carbon or 0.3 part organic nitrogen. This standard would have prevented the discharge of any but the most perfectly purified effluents. The recommendations were never embodied in the law, and never since that time have the established standards been so exacting. The following standards, all expressed in parts per 100,000, have almost legal force in the various districts of England (Rideal, 1902) — Thames Conservancy: organic carbon 3.0, organic nitrogen 1.1; Derbyshire County Council: albuminoid ammonia 0.1, oxygen absorbed 1.0; Ribble Board: albuminoid ammonia 0.1, oxygen absorbed 2.0; Mersey and Irwell: albuminoid ammonia .14, oxygen absorbed 1.4.

It will be seen at once that mere dilution of the effluent will bring it within the limits of any such standards, which are based upon actual amounts of organic matter present. It is even claimed by the sanitary inspectors that certain manufacturers use this method as their sole means of bringing their waste liquors down to the required standard.

Since the introduction of the more recent biological processes our ideas of purity of effluents have been gradually changing. In many of these processes, but most notably in the case of the continuous, or trickling, filter, a large amount of organic matter is passed through the filter, which upon examination generally proves to be of a peaty or humus nature and incapable of further putrefactive change. Aside from the possibility of such material creating a nuisance by forming deposits behind milldams or in the lower reaches of the stream, it appears to be entirely harmless and nonoffensive. Chemical analysis fails to distinguish between the ordinary putrescible matter of sewage and this non-putrescible material which results from the treatment of the sewage in the manner indicated. This has led to the introduction of putrescibility, or incubation, tests which are now so commonly used

These depend in general upon the storage of the effluent in a bottle at summer temperature and out of contact with the air for a period of several days. Certain tests are then made upon this incubated sample to determine if it has undergone putrefaction. The determination of the oxygen consumed before and after incubation is the one most frequently employed. Many chemists determine the loss of dissolved oxygen and of nitrates either in the original effluent or after mixing it with certain quantities of aërated water or nitrate solution.

Attention has also been called to the value of the nitrates in an effluent. Gayon and Dupetite (1886) have shown that denitrification is a direct combustion of organic carbon at the expense of the oxygen of the nitrates. Experiments of Adney and of Letts tend to confirm this view. It is also brought out by these investigators that the free dissolved oxygen likewise takes part in the reactions, carbon dioxide being evolved in amount corresponding to the free oxygen used up. Thus instead of adhering to the older view that all organic matter is harmful and must be kept below a certain maximum standard value, the more recent practice is to balance the available oxygen against the organic matter, and, if the former be found in excess, to consider the effluent satisfactory. The question remaining to be settled, and on which there are many views, is just how much of the oxygen is available and how much of the organic matter requires oxidation.

These and other considerations have led to the construction by Rideal (1902) of a formula for the discharge of effluents into a stream, which he proposes as a practical standard of purity for effluents. This formula is:—

$$C = \frac{XO}{(M-N)S},$$

in which

X = Flow of the stream in hectoliters per minute.

O = Grams of free oxygen in 1 hectoliter

S = Hectoliters of effluent discharged per minute.

M = Grams of oxygen required to consume the organic matter in 1 hectoliter of effluent as determined by the permanganate test, boiling for four hours and deducting for the nitrites.

N = Grams of available oxygen as free oxygen, nitrate, and nitrite ($2O_2$ for N_2O_5, O_2 for N_2O_3).

C = Ratio between the amount of oxygen in the stream and the amount of this required to oxidize the organic matter.

This formula serves to distinguish three possible cases. If C be negative, the effluent not only will not putrefy by itself, but by virtue of its excess of available oxygen will tend to improve the condition of the stream, if the latter be already polluted. If C be greater than unity, the effluent will draw upon the oxidizing power of the stream, diminishing the power of the latter to deal successfully with further pollution; but in this case the stream will not itself become foul from this effluent. If C be positive, but less than unity, the stream will be overburdened by the addition of the effluent, and will become foul.

In England, where the subject of streams pollution has received careful study, the opinions of the experts on this question of standards vary greatly. The late Sir Edward Frankland (1902), in his testimony before the Royal Sewage Commission, restated the proposition advanced by him in 1874, that "there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation." Frankland also expressed distrust of the incubation test, believing it to be unreliable. On the other hand, the position taken by Rideal, that all free oxygen, as well as the oxygen of the nitrates and nitrites, is available to complete the oxidation of the remaining organic matter, was supported by much of the testimony. The same views are embodied in a test proposed by Adney (1902), who would incubate a sample of the effluent after diluting with river water in the proportion in which the two are mixed in the river. Then if no putrefaction occurs the effluent is satisfactory.

This test represents the extreme view of that school of sanitarians who hold that, if a partially purified effluent can be supplied with sufficient available oxygen for the complete oxidation of the remaining organic matter, it may with safety be discharged into the stream, and the purification will be completely carried out within the stream. In justice to this view, it should be stated that what is here attempted is apparently not the protection of the streams from pollution by disease germs so much as the prevention of an apparent nuisance in, or fouling of, the stream. The evident intention is to keep the stream in such a condition that it may be rendered fit for domestic use by further purification of the water.

With our present knowledge, at least, this would seem to be the wiser provision. We know little, unfortunately, of the viability of disease organisms in sewage and of the effect of purification treatment upon them. While the ideal condition, and the one toward which sanitarians should ever be working, is the perfect purification of sewage from all pathogenic bacteria before discharge, it may nevertheless be better economy, with our present information, so to purify our sewage as to prevent it from seriously fouling the streams and to thoroughly purify all waters taken from them for domestic use. With the idea, therefore, of interpreting our analyses of effluents in accordance with this view, let us examine our analytical procedure in connection with the purification processes to see what significance each of the substances determined has upon the interpretation of the analysis of an effluent. At the same time the fact must not be overlooked that practically perfect purification from the bacterial point of view is entirely feasible, and in many cases desirable. The question of the interpretation of slow-sand-filter effluents will, therefore, naturally be included in the present discussion.

NITROGEN

According as the conditions of the purification process are aërobic or anaërobic, the nitrogen of the organic molecule may follow one or the other of two very different courses. In the slow sand filter and also in the percolating, or trickling, filter, in both of which types there is a plentiful supply of oxygen, the course of all the nitrogen seems to be from organic molecule to ammonia, and thence to nitrites and nitrates. In a very good sand filter as much as 99 per cent. of the organic nitrogen may be thus accounted for. On the other hand, Farrell and the writer (1905) have recently shown that in the contact system of purification, while as much as 25 per cent. of the total nitrogen may follow this course, a large part of the remainder is converted, under the anaërobic conditions of the reduction phase, into the amine form, and that these amines in turn react with the nitrites previously formed. This reaction causes a liberation of a large percentage of the total nitrogen in the form of the free gas. As much as 50 per cent. of the total may thus disappear. In the septic tank also nitrogen is liberated, but in this case the liberation is brought about by the direct action of the microörganisms upon the organic molecule. Kinnicutt and Eddy (1901) have published the results of what is probably the most careful study ever made of the amount and composition of the gas given off in the septic tank. As a result of their work upon the Worcester sewage, extending over a period of a little over two years, they found for the first fifteen months the average amount of gas evolved was 2.3 gallons per 100 gallons of sewage, and that of this gas 32 per cent. was nitrogen. A simple calculation shows this amount to represent 9.8 parts per million of sewage. The total nitrogen value for the raw sewage, as given by Eddy (1901), is 42.5 parts per million, so that 23 per cent. of the total is evolved in the tank as nitrogen gas. During the following year the average results similarly calculated are 8.5 parts per million evolved, or 17 per cent. of the total nitrogen of the sewage. The latter figure itself is not given for that year, and is here calculated approximately by the formula proposed by Fuller (1903), which is,

$$\text{Total organic nitrogen} = \frac{12 \times (\text{albuminoid nitrogen})^2}{\text{ammoniacal nitrogen}}.$$

Similar calculation made upon some results obtained by Clark (1900) on the Lawrence sewage shows an evolution of nine parts per million of nitrogen in a sewage which contains approximately forty parts per million of nitrogen as calculated by the above formula. The nitrogen evolved in this case is therefore about 22 per cent. of the total.

In Manchester, England, Fowler (1901) has made some analyses and measurements of the gas in a septic tank. His results, calculated into parts of nitrogen per million, give 12.5 parts. Averages of the raw sewage are not given, but, judging from the septic tank effluent, the sewage is of about the same strength as that of Lawrence.

Knowledge of the actual amount of nitrogen escaping from the septic tank or from a contact filter is obviously of great importance, and the value of total nitrogen determination as an index of the work of these processes is evident:

The Free Ammonia.—The free ammonia being a transition stage in the purification process is not of much significance in those rapid processes of treatment where a large amount of ammonia is produced in a short time. While it is strictly an inorganic substance, and in every way harmless, yet the fact must not be overlooked that it is not a stable compound when discharged into a stream. All the free ammonia must be oxidized at the expense of the free oxygen of the stream, and its effect in thus reducing the power of the stream to further purify organic matter must be allowed for. This fact is not considered in Rideal's formula previously given. In very pure effluents, such as those from sand filters, the free ammonia, being extremely low, is a valuable index of the work of the filter. In such cases it may be said that it runs very nearly parallel with the organic nitrogen as well as with the bacteria.

Nitrites. — The nitrites are likewise transition substances, and are extremely unstable. In filters of the oxidizing type, nitrites are a valuable indication of the condition of the filter. When such a filter is running at its best, the nitrites will, as a rule, be low. A marked increase in the nitrite value is then an indication that something has gone wrong with the filter. Considered with reference to the stream, they are of value in that they possess available oxygen, although as a rule the amount of nitrites present is too small to be of any value in this respect. Their great importance in the reactions of the contact filter has already been alluded to.

Nitrates. — Nitrates are the final product of the oxidation of the organic nitrogen. Their appearance in sand and trickling filters is, therefore, of great significance, in that they indicate the actual amount of work done by the filter. Their relation to the quality of the effluent is also important. They carry the largest amount of the available oxygen of the effluent, and it is now believed by most authorities that they may be entirely consumed in the process of secondary oxidation, which takes place in the stream after the discharge of the effluent. Any arbitrary standard for purity for effluents from such filters should therefore contain, in addition to a maximum allowable amount of organic matter, a minimum amount of nitrates. In such a case mere dilution of an effluent could never bring it to the desired condition, while with high nitrates an effluent will not generally become foul or offensive by secondary putrefaction.

Authorities are not yet in agreement as to the significance of nitrates in the contact filter effluent. This point has been discussed in detail in the paper on the contact filter previously referred to (Phelps and Farrell, 1905), and will not be taken up here. The writer's opinion is that since nitrates are used up in the work of the filter, their appearance in the effluent merely indicates that an excess has been formed, and that if necessary the filter may be worked harder. Perfectly stable effluents may be obtained practically free from nitrates.

CARBON

The organic carbon is determined only partially by the oxygen-consumed test. While this test has a certain value in the comparison of effluents from similar filters, and especially as a quick method for controlling a filter, it has no scientific basis whatever, and the relation of its results to the total carbon is, so far as the writer is aware, unknown. In a few experiments made by Mr. Roger L. Rice under the writer's direction it was found that the percentage of the total carbon of various organic substances given by this test varied all the way from a few per cent. in the case of cane sugar to 100 per cent. in the case of such bodies as ammonium oxalate. The futility, therefore, of attempting to calculate the efficiency of a process upon the basis of the test is apparent. It has been claimed that with a four hours' boiling this process determines the total carbon, and Rideal has worked out his formula for purity of effluents on this assumption. The subject of the determination of the total carbon by a method which shall be fairly accurate and at the same time sufficiently rapid and easy for routine sewage work is one which should receive the attention of sewage chemists. The question whether or not the oxygen consumed as now determined, or as it may be determined by some modification of the present process, bears any significant relation to the total can then be considered, and it is very possible that a relation may be obtained which shall show the ease with which the organic carbon can be oxidized. This latter point is, of course, an important one in the consideration of the stability of the effluent. The oxygen-consumed determination is of undoubted value in the putrescibility tests, which will be considered later.

OXYGEN

Free dissolved oxygen in the effluent represents a reserve oxidizing power by which the effluent can further purify itself. Its presence also indicates that there has been a sufficient supply of this necessary element during the process of purification. The effluents of oxidizing filters, sand and trickling filters, should always contain free oxygen. If all the oxygen is used up, then the process is not being properly worked. In the contact-filter effluent the free oxygen has another significance. The supply of oxygen being necessarily somewhat limited in this type of filter, it will become most completely exhausted in that filter which is doing the most work. We find that this is actually the case at the Sewage Experiment Station treating Boston sewage. Our best contact-filter effluents are, as a rule, free from dissolved oxygen, while others, although less well purified, contain oxygen. This effluent, which is free from dissolved oxygen, might be looked upon with suspicion but that it contains high nitrates, and has thus an available reserve of oxygen in another form. There may be some doubt as to which of these two effluents is really the better. They would doubtless both give similar values for C in Rideal's formula. Incubation tests are strongly in favor of the one containing nitrates.

PUTRESCIBILITY TESTS

By putrescibility we denote that property of the organic matter in a sewage or effluent which causes it, under certain conditions, to undergo putrefactive change. Thus gelatin is a putrescible substance, while peat is a good example of a non-putrescible, or stable, substance. For the purposes of sewage work, the organic matter dealt with may be roughly grouped into these two classes, for it is now pretty generally conceded that, in addition to the readily putrescible organic matter which characterizes sewages, there is also found in effluents organic matter of the other class, that is, stable organic matter. Bodies belonging to this latter group may already exist to some extent in the raw sewage, and they are the characteristic end-products of the rapid oxidation of the sewage in a trickling filter. They are not produced appreciably in the anaërobic decompositions of the septic tank, and would, therefore, appear to be the result of the direct oxidation of the organic molecule rather than of its hydrolitic cleavage. This view may be illustrated by the two following hypothetical reactions:—

$$\text{Oxidation, } 2R-N=R' + 3O_2 = R-O-R + 2R'=O + N_2O_3.$$
$$\text{Hydrolysis, } R-N=R' + H_2O = R-OH + R'=NH.$$

In other words, hydrolytic cleavage produces amines and complex, perhaps unsaturated, hydroxyl bodies, while oxidation produces ultimately oxides of nitrogen and organic molecules which do not readily take up more oxygen.

Water analysts feel strongly the need of distinguishing between these two classes of bodies in potable waters represented by animal pollution on the one hand and by vegetable extractive matter on the other. Many attempts have been made to devise an analytical process for this purpose. Woodman (1898) has proposed a method which is worthy of wider adoption. He would determine the oxygen consumed by the regular method from permanganate and again from chromic acid.

The ratio between these two values is a characteristic one for each of the two classes of material. The water analyst, however, has other determinations upon which he can rely to aid in his interpretation. The chloriné, nitrites, and nitrates each have their own significance, and help to explain the origin of the organic matter.

In sewage analysis nothing in the ordinary procedure serves to give any clew to this question of the character of the organic matter. Therefore about 1895 Scudder (1902) devised as a simple method of studying this point the test which has since come to be known as the incubator test. In its earliest form this test consisted in completely filling a bottle with the effluent and keeping it stoppered at a warm summer temperature for a few days. If it was then free from odor and from all signs of decomposition, it was considered nonputrescible. Later Scudder placed this test upon a more scientific basis by determining the oxygen consumed from permanganate in the cold in three minutes, the dissolved oxygen and the nitrates both before and after incubation. A putrescible effluent as defined by him will have lost part of or all its dissolved oxygen and nitrates, and will absorb an increased amount of oxygen from permanganate.

The writer's experience with the incubation test upon many kinds of effluents leads him to believe that the observed changes in the amount of available oxygen and in the oxygen-consuming power of the effluent during incubation serve to indicate three different conditions of the effluents, rather than two only, and that the interpretation of the test from this point of view makes it the most valuable one in our analytical procedure. The following classification of the results of the test will make this view plain: —

1. There is no loss of available oxygen during the incubation.
2. There is loss of available oxygen.

a. The loss is only partial. The oxygen-consumed value is unchanged or diminished. The effluent remains clear without the production of disagreeable odor.

b. The loss is total. The oxygen-consumed value is increased. Putrefaction has occurred with the production of disagreeable odors, and usually of a dark sediment.

In case 1 the organic matter is stable, or nonputrescible, in the true sense of the word. Such an effluent would pass the incubation test in its strictest form as recommended by Scudder. Case 2 *a* represents an effluent whose organic matter is not completely stable. The putrescibility of this organic matter is not determined by the test, since anaërobic conditions have not been established. This material might, under such conditions, have become putrescent, but the supply of available oxygen in the effluent is more than sufficient to render it stable and nonputrescent. Although the available oxygen is diminished and the effluent would not, therefore, pass the test as used by Scudder, it is nevertheless apparent that it contains within itself the power to complete its own purification, and thus could not under any conditions become foul. Case 2 *b* is an example of an effluent which cannot complete its own purification, and would draw upon the purifying power of the stream. Its effect upon the stream, therefore, would depend upon other considerations, namely, relative volumes of the stream and of the effluent, character of the stream as regards previous pollution and available oxygen, etc. For the further study of such an effluent Adney's proposed test will be of service. This test consists in mixing the effluent with the water of the stream in the proportion of the relative volumes of their flows, and then incubating. Whether or not the stream will be able to complete the oxidation of the effluent will be shown by this test. But one must not overlook the fact that one is working here on a very narrow margin of safety, and careful consideration must be given to the possible seasonal variations in the quality and flow of the stream. In general, effluents of this character ought not to be discharged. They constitute pollution even when no immediate nuisance is produced. Their effect upon the river is cumulative, and in the case of a stream receiving such effluents from a number of communities the first discharge might be of untreated sewage, while the communities lower down would be obliged to produce a very pure effluent in order to prevent fouling of the stream.

In carrying out the determinations connected with the incubation test certain special methods of procedure are necessary. For example, it is found that the determination of the oxygen consumed by the shorter English method — three minutes in the cold — rather than by the hot method emphasizes greatly the changes occurring during the incubation. The writer has also found it quite necessary to determine the amount of permanganate which is instantly used up in the cold. This instantaneous value determines the hydrogen sulphide, ferrous salts, and other products of reduction accompanying anaërobic fermentation, and includes also the nitrites, if any are present. After correcting this value for the nitrites, any marked increase after incubation is indicative of putrefaction having taken place. The determination of the free oxygen and the nitrates after incubation will be unnecessary unless it be desired to distinguish between Class 1 and Class 2 *a* as described. In the writer's opinion no such separation is necessary, since effluents of either class are either stable or will rapidly become so. In fact, it is only effluents of the highest degree of purity which will fall into Class 1. Such effluents will, as a rule, be produced only when necessary for the protection of water supplies, and in such cases a much more delicate test, such as the bacteriological examination, would naturally be relied upon.

It will be observed that the conditions established by these incubation tests correspond with the three conditions defined by Rideal's formula (page 126), the difference lying in the way in which the oxygen required for complete oxidation is determined. The use of such a formula as a substitute for the incubation test would be highly desirable. It must first be shown, however, that the oxygen consumed from permanganate is practically the same as that used up during incubation. Obviously by boiling for four hours with permanganate a much greater amount is used up than would be required by the effluent to render it stable. The Lawrence method of boiling for two minutes would probably give deficient values. This is a point worthy of further study, since it determines at once the most important character of the effluent — its stability.

FILTERED AND UNFILTERED SAMPLES. TURBIDITY, COLOR

In effluents showing an appreciable turbidity, the determination of the total nitrogen upon the sample after filtration through paper will give additional information. Since it may be assumed that a large part of the suspended solids will eventually find its way to the bed of the stream, this information will be of practical value to the analyst. The writer has found the determination of the putrescibility upon such a filtered sample to be also of service. In some cases a mere settling out of the grosser matter will serve to change the character of the effluent from one slightly putrescible to one thoroughly satisfactory. As a measure of the absolute amount of suspended matter in the effluent, a quantitative reading of the turbidity as described in an earlier paper will be of service.

The color of clear effluents of high purity often serves as a useful indication of slight changes in the work of the filter. Where a high degree of purification is not attempted the color of the effluent is of no value whatever.

The odor of the effluent is often of significance to the analyst, although the difficulty of correctly describing such an odor in intelligible terms lessens the value of this test as a matter of record. The writer has used a set of terms for odors in sewages and effluents which are sufficiently self-explanatory to any other analyst engaged in the same work to render them of some service. They are as follows: *Sewage*, the odor of fresh sewage as it flows in a city sewer, especially in winter. *Septic*, the characteristic odor of septic sewage, which often persists after passage through the filter. *Musty*, as used in water analysis; generally characteristic of contact filters. *Earthy*, the odor of fresh, clean earth, characteristic of trickling filter effluents. *Vegetable*, as used in water analysis, characteristic of well-purified sand-filter effluents. The numerical expression of the intensity of the odor, as recommended by Whipple (1901), is used in connection with these terms with fairly satisfactory results. The odor after incubation is obviously of great value in the interpretation of that test.

BACTERIA

When we consider that the removal of pathogenic organisms from the sewage is one of the prime reasons for its purification, it is unfortunate that the advance of knowledge in this particular subject has been very much slower than on the purely chemical and engineering sides. The actual removal of pathogenic organism from water by sand filtration has been experimentally demonstrated, and a study of the vital statistics of certain localities before and after purification of a polluted water supply leaves no room to doubt that a fairly complete removal of such organisms by sand filtration is possible. It might thus very well appear that in the case of sewage a careful purification through sand filters, which reduces the total bacteria to a figure permissible in a filtered water supply, will also have effectively removed the pathogenic forms.

The organisms supposed to be the cause of nitrification in the filters have been extensively investigated. Qualitative studies other than these are not very often made. What little information exists at present on this important subject is for the most part too meagre to allow of any general conclusions as to the significance of any given organism or groups of organisms in an effluent. One important exception to this statement, however, must be made in the case of the organisms *Bacillus coli* and *B. enteritidis.* The occurrence of these two organisms in the effluents of sewage filters has been made the subject of an extensive study by Houston and McGowan (1902), who show that in a series covering a wide range from raw sewage to completely purified effluents the unpurified organic matter of the effluent is roughly proportional to the numbers of colon bacilli, to the numbers of *B. enteritidis,* and to the numbers of organisms producing gas in sugar gelatin. As a practical test they have selected the latter group of organisms, whose approximate numbers can readily be estimated by the dilution method. The practical standard of purity proposed is that the effluent shall not contain over ten of these gas-producing organisms per cubic centimeter. In the extensive comparison made this standard in every case served to distinguish between the satisfactory and unsatisfactory effluents.

Another important line of work has been indicated by Clark and Gage (1905). These investigators have found that a large percentage of the total number of organisms passing through a sewage filter consists of a relatively small number of species. These species are carefully counted on the gelatin plate, and a number of each kind fished for further study. In this study the ability of each organism to liquefy gelatin, ammonify peptone, oxidize ammonia to nitrites and nitrates, and to reduce nitrates to nitrites, ammonia, and free nitrogen is determined quantitatively. The quantitative power of any organism to produce ammonia from peptone times the number of organisms of that kind present in a cubic centimeter of the effluent is the ammonifying power of that organism in the effluent. The sum of the ammonifying powers of all the organisms present constitutes the ammonifying coefficient of the effluent. Similar coefficients are determined for each of the other functions mentioned. It is too early to venture an opinion upon this work. Since, however, we are dealing with life processes, it would seem that the proper method of determining the properties of an effluent would be a study of the life within the effluent and the chemical changes which the living organisms are capable of producing, or what the authors aptly term the "biochemistry" of the effluent.

Mere quantitative counts of the organisms in the effluent are of no significance except in those effluents in which a high degree of purity is expected. In such cases the number of organisms present serves as a valuable index of the amount of organic matter in the water.

OTHER PROPOSED TESTS

Many other tests of minor importance have been proposed for the rapid determination of the character of the effluent. Such tests for the most part lack the merit of being based upon any scientific principle, and are, as a rule, only used for the guidance of the workmen in the control of the filter plant.

At Leeds, England (Harding, 1902), the effluents are passed through small basins in which fish are kept. The fact that fish are thus able to live is taken as evidence that the effluent is satisfactory. Obviously the ability of fish to live in an effluent signifies merely that there is an abundant supply of oxygen and an absence of any great amount of turbidity, facts which could be equally well shown by very simple tests.

In these same basins certain microscopic animals and plants are often found, and upon the character of such growths Walker (1902) has based an interesting biological test for the quality of the effluent. For example, he found that the best effluents, such as those from double contact systems high in nitrates, support a copious growth of the *Chlorophyceæ*, notably *Stigeoclonium* and *Microspira*, while *Oscillaria* and other *Cyanophyceæ* are generally present in small amounts or altogether absent. In slightly inferior effluents these blue-greens predominate, together with *infusoria* and *rotifers*. Still poorer effluents were found to be characterized by the presence of *Beggiatoa* and the infusoria, *Carchesium* and *Vorticella*.

The Derbyshire County Council recommend a "shake test." In this test the effluent is vigorously shaken in a bottle for one minute. In a satisfactory effluent the froth should disappear within three seconds. The significance of this test is not apparent.

Barwise (1904) suggests that the process of purification is accompanied by the conversion of ammonium carbonate into nitrous and nitric acids, a change from alkaline to acid reaction. He therefore recommends the determination of the alkalinity in the raw sewage and in the effluent as a measure of the purification. In sewages containing much cellulose, however, he found the test to be unreliable on account of the production of acids from the cellulose.

SUMMARY AND CONCLUSION

Summarizing briefly the most important points in the analysis of a sewage-filter effluent, it may be said that the determination of the nitrogen in all its forms is of first importance, not alone in indicating the extent of the purification, but as an index of the stability of the effluent; that the determination of the total organic carbon, or its roughly relative estimation by the oxygen-consumed test, ranks next in significance, representing material that still requires oxidation; that the dissolved oxygen is of great significance both as to the condition of the filter and the stability of the effluent; and that a study of the changes occurring during incubation serves to reënforce the analytical data, and is in reality the ultimate criterion upon which the interpretation of such data depends. The value of bacteriological data as indicative of the quality of the effluent is still an unknown quantity, although the writer is inclined to believe that the determination of specific coefficients, as described by Clark and Gage, may eventually become the standard against which we may check our simpler laboratory methods. Such extensive studies are obviously not available in the routine work of the analyst for sewage works, but are of the greatest importance in enabling us to understand the processes with which we are dealing and correctly to interpret our analytical data.

In the following specimen analysis of an effluent are included the important determinations which have been described in the preceding pages.

SPECIMEN ANALYSIS

(Parts per million)

	Total.	Dissolved.	Suspended.	After incubation. Five days at 37°.
NITROGEN:				
Total	50.5	44.5	6.0	. .
Organic	16.0	10.0	6.0	. .
As NH_3	11.0	11.0	. .	. .
As N_2O_5	1.5	1.5	. .	1.0
As N_2O_3	22.0	22.0	. .	15.0
CARBON:				
Total	100.0	70.0	30.0	. .
By $KMnO_4$:				
Cold. Instantaneous	0.1	. .	. .	0.1
Three minutes	0.6	. .	. .	0.4
Hot. Thirty minutes	12.4	8.0	4.4	. .
OXYGEN:				
Dissolved	7.2	. .	. .	5.0
TURBIDITY:				
Total	125.0	. .	. .	. .
On standing	25.0	. .	. .	. .
Sediment (diff.)	100.0	. .	. .	. .
COLOR	. .	. .	. .	. .
ODOR	3 earthy		. .	1 musty

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A WINTER VISIT TO SOME SEWAGE DISPOSAL PLANTS IN OHIO, WISCONSIN AND ILLINOIS.

By C.-E. A. Winslow, Member of the Boston Society of Civil Engineers.

[Read before the Sanitary Section of the Society, April 5, 1905.]

We must go west in order to learn the new things in sewage purification. In New England the classic Lawrence experiments of 1890 have firmly grounded our theory, and the mantle of glacial drift makes our practice easy. Beyond the range of the Appalachians all is changed. The character of sewages and the available materials for treating them are alike different. Old England rather than New England furnishes comparable conditions and we find a general development of the newer British processes through the Mississippi Valley. Even these methods, however, prove not wholly suited to their new conditions. Many of them are failures, on account of climate, on account of varying sewages, on account of the political conditions which make it difficult to secure efficient public service in American municipalities. No saying, however, is more true than that "We learn by making mistakes." They are learning a great deal in Ohio and Wisconsin and Illinois about the rapid methods of sewage purification. Columbus is doing for such processes what Lawrence did for sand filtration fifteen years ago. The whole region is an inspiring one for the sanitarian to visit.

In a short trip through the Middle West during January of the present year I had the opportunity of seeing some dozen sewage purification plants of various types under the most unfavorable conditions of practical operation, and I have been asked to tell you what I saw, in the hope that even such a fragmentary report may help us to estimate the success of the newer processes of sewage treatment in this country and their promise for the future.

From the admirable report by R. W. Pratt on Ohio sewage plants in 1903 it appears that there were then eleven sand filter plants in the state of Ohio, with which no sort of preliminary treatment was used. One was a subsurface system; one was wholly, and two were partly, given up to broad irrigation. All but three were small plants serving institutions, and the total population connected with the eleven plants was only 21 000. One of the best of these intermittent filters is that at the Ohio State

Reformatory at Mansfield, O. (Pratt, 1905). The sewage from a population of six or seven hundred persons, amounting to 60 000 to 70 000 gal. per day, is discharged on seven small beds with a total area of 1.1 acres. The beds are built of friable sandstone taken from a cliff near by and crushed by the prisoners. The effluent is said by the engineer of the State Board of Health to be of good quality, but considerable trouble has been experienced in keeping the beds clear in winter. They were originally plowed with deep furrows 1.5 ft. high, and 4 ft. apart, but this worked badly, as the available area was unduly decreased and the beds froze. At the time of my visit small furrows 6 in. high were giving poor results, the beds being half frozen and covered with slush. Probably a judicious mean might prove more favorable.

The only other intermittent filtration plant I saw in the West illustrated the difficulties which attend this process where ample areas of sand cannot be obtained. Oberlin, O. (Pratt, 1905), is a village of 5 000 inhabitants lying 30 miles west of the city of Cleveland and 10 miles from the shore of Lake Erie. The first sewers were constructed in 1892 and two years later a field in the outskirts of the town was laid out for sewage disposal. Six acres of fine sandy loam were available to receive gravity flow, of which three acres and a half were underdrained for intermittent filtration and an acre and three-quarters merely ditched for broad irrigation. Two settling basins, 3 ft. deep and 10 ft. by 30 ft. in area, were constructed by excavating pits and boarding up the sides, and from these the sewage overflowed through distributing ditches on the beds. Sludge from the pits was pumped out and dumped near by; it amounted to some 4 per cent. of the sewage treated. For some years the plant worked well while the average flow of sewage remained below 100 000 gal. per day. Since 1902, however, it has rapidly increased, to some 250 000 gallons at the present time, and the beds have become heavily overtaxed. In order to prevent serious pollution of the creek below, the system has been converted into a sort of chemical precipitation plant by a process probably unique in the history of sewage purification. During the warmer nine months of the year chemicals are discharged into the main sewer of the town, about 125 lb. of ferrous sulphate and 150 lb. of lime in the form of hydrate, by automatic devices located respectively at the upper end and the middle of the system; sedimentation takes place in the pits and on the beds which are generally clogged and a considerable nuisance is created. At the time of my visit in January no chemicals were being used and the sewage was simply standing on the beds and overflowing into the creek, turning the whole area into a noxious swamp.

The reason for the failure of this Oberlin plant is, of course, the absence of a sufficient area of land really suitable for intermittent filtration. In this respect it is fairly typical of general conditions throughout the Middle West. Sand treatment alone is inadequate over most of this great region; and it has been necessary to seek some preliminary process which should make possible filtration at more rapid rates. As in England, chemical treatment first suggested itself for this purpose and a number of plants have been installed, somewhat less crude than the one just described. Glenville, O., has chemical treatment preparatory to passage through the contact bed, and at Alliance, O. (9 500 population), and Canton, O. (32 000 population), chemical precipitation is the only method used. Both the latter plants are said to be well operated and to yield fairly satisfactory results (Pratt, 1905).

As in other localities, however, the disadvantages of the chemical treatment have been made manifest. Poor effluents, offensive sludge and costly operation prove almost inseperable from this method. It was natural, therefore, that engineers should turn their attention to some better method for removing suspended solids. It soon appeared that such a method could be developed by the regulation of the anaërobic ripening process which goes on in every cesspool. Such a preliminary ripening liquefies a considerable portion of the solid material in sewage. According to its advocates it does the work of chemical precipitation without the cost of chemicals and with a diminution of objectionable sludge. As championed by Donald Cameron of Exeter, who gave it the picturesque name of the "septic tank," this anaërobic process seemed most promising; and nowhere has it been more cordially received than in the Middle West. Indeed, there may almost be said to be a cult of the septic tank in Illinois and Wisconsin. Even in small towns where no system of sewage purification is really essential the possession of a septic tank is a matter of municipal pride; in some half dozen towns this is the only method of treatment, the clarified effluent being discharged into the nearest body of water without any attempt at nitrification.

I saw one such system at Highland Park, a lake shore suburb of Chicago with a population of about 4 000. Two-thirds of the village drains westward and the sewage from this region has been treated for some years by the septic tank method. The new tank which I saw in operation was put in by W. S. Shields only three months ago, and takes a portion of the sewage from the eastern part of the village along the lake front. Two other outlets from this region discharge into the lake without treatment. The tank is covered and underground and in somewhat close proximity to the pumping station of the waterworks. At the time of my visit its effluent contained considerable suspended matter, but as the tank had been in operation for so short a time and during cold weather it could not have attained its normal condition. With regard to the wisdom of treating sewage by the septic tank alone without a subsequent aërobic process, I must confess myself somewhat skeptical. There may be cases where raw sewage would cause a nuisance, while the clarified septic effluent is sufficiently improved to do no harm; but such a balance of conditions must be rare.

In general, of course, the septic tank treatment is only used as a preliminary to intermittent or contract filtration, and on these principles many admirable plants have been constructed and are in operation in the Middle West. Of the first type I saw three good examples, one at Lake Forest, Ill., and two at Wauwatosa, Wis. The Lake Forest plant was designed in 1902 by J. W. Alvord and W. S. Shields (Alvord, —) to care for a flow of 350 000 gal. a day. A population of 1 800 at that time has now increased to about 3 000, and it is probable that the plant is nearing its full capacity. It is beautifully located at the bottom of a bluff on the shore of Lake Michigan. The sewage first flows through an open brick septic tank protected from abrupt temperature changes by a light brick structure and divided into five compartments so arranged that by various combinations the period of septic action may be adjusted to suit varying conditions. (Fig. 1.) Mr. Alvord has pointed out the desirability of so building tanks that the period of fermentation may be altered with changes in temperature and in the volume and composition of the sewage; and most of his recent septic plants are built upon this principle. The theory, upon which this practice rests, is that a too brief period fails to remove a maximum of solid material while over-prolonged septic action produces an effluent which is for some reason hard to nitrify. It is, unfortunately, almost impossible to secure proper expert supervision of sewage disposal under present conditions, and at all the plants which I visited the operation of the "elastic tank" had been practically abandonedand the whole available area was used as a single tank.

At Lake Forest with a tank 35 ft. by 20 ft. in area and 8 ft. deep, and a capacity of 50 000 gal., this method of operation gave a period of about four hours. One-third of the tank back of the first baffles was covered with a very heavy layer of frozen scum while the rest of the tank showed only half an inch of light scum. The effluent from the tank which runs over an aerating weir into a dosing chamber of 7 000 gal. capacity, appeared to be a good septic sewage, dark colored and with only very fine suspended particles. The tank has never been cleaned out.

One important feature of the western sewage plants is the genetal attempt to introduce automatic devices for regulating flow and for dosing filter beds. The danger from the failure of such devices is, of course, always considerable and they absolutely require periodic expert supervision; but by and large I am inclined to think even a fair automatic device will prove as reliable as the average city employee. The apparatus used at Lake Forest for dosing the sand filters is an extremely ingenious one. A float in the dosing chambers lifts a cannon ball in one of a set of hollow wooden columns arranged in series, and at a certain height the ball rolls through a trough from one column to the next, in its passage striking a catch which opens an air valve attached to one of ten bell syphons in the dosing chamber. Each syphon discharges on one of the ten sand filters which may thus be dosed in rotation. At the time of my visit the automatic device had been purposely thrown out of gear so that the sewage was flowing continuously upon one bed, perhaps with the idea of preventing the surface from freezing.

The sand filters are each 3 200 sq. ft. in area, the total area being three-fourths of an acre, and the rate is therefore now over 400 000 gal. per acre per day. The filtering material, the natural beach sand of Lake Michigan, is quite fine, 85 per cent. passing a sieve with 40 meshes to the inch, and 42 per cent. passing a sieve with 60 meshes to the inch. The distributing carriers used here and elsewhere by Messrs. Alvord and Shields struck me as admirable, — for small beds superior, perhaps, to those which are more common in the East. They are straight or branched troughs made of two upright sides of 2-in. plank, resting on a similar bottom plank with 3-in. square holes at the base of the sides, spaced about 2 ft. apart. Like all distributing devices their operation requires sufficient head to yield a good gush of sewage; given this they should be perfectly satisfactory.

With the dosing device deliberately thrown out of operation, as I have mentioned, the Lake Forest plant was not doing wholly satisfactory work. Sewage was standing several inches deep on the one bed which could receive it, and the effluent as it flowed off to the lake was dark colored and appeared imperfectly purified.

A plant very similar to that at Lake Forest was built four years ago by Alvord and Shields for the town of Wauwatosa, Wis. (Alvord, —). The population of the town is about 3,000, but there are not more than 200 connections with the sewer system, including a sanatorium, a pickle factory and a chemical works. The flow is said to be about 100 000 gal. a day. The sewage first enters a concrete septic tank sheltered as at Lake Forest by a brick roof. The tank is approximately 15 ft. by 50 ft. by 10 ft. deep, with a capacity of 40 000 gal. It was originally provided with three longitudinal partitions, but the sewage is now run straight through, giving a storage period of 10 hr. At the time of my visit the first tenth of the tank behind the first baffle bore 6 in. to 8 in. of very heavy scum, and a considerable accumulation of sediment could be felt at the bottom. The town engineer informed me that the tank must be cleaned out twice a year, a quantity of combined scum and sludge equal to half its capacity being removed by dipping out with pails and by the use of a small rotary pump. The effluent appeared like a good septic sewage, dark gray in color and with no large particles.

The septic effluent should pass to a dosing chamber in a separate small brick structure where it may be discharged on sand beds by the same device in use at Lake Forest. (Fig. 3.) The beds are 6 in number, 30 ft. by 60 ft., with a combined area of one-fourth acre, thus giving a rate of 400 000 gal. The sand used is coarse and the results obtained are said to be excellent. In cold weather, however, it is the practice of the authorities to discharge the septic effluent directly into Menominee Creek without filtration. This has not been compelled by any failure of the plant, but is done to avoid the expense of caring for the surface of the beds during a season when the septic tank effluent will not produce a serious nuisance in the river below. Like the use of storm overflows such a custom does not commend itself to the sanitarian; but from the standpoint of the city engineer it may be good economy.

In the same town is a larger plant of almost exactly similar construction (Shields, 1904), which shows what good results can be obtained by careful and efficient operation. The Wauwatosa County Institutions form a group of five buildings, including two insane hospitals, an almshouse, a county hospital and a home for dependent children. The total population is about 3 500 and the water consumption, 400 000 gal. per day. A chemical precipitation system was put in in 1888, the dosing house and coagulating basin still remaining as its monument. Then a septic tank alone was installed; but it proved unsatisfactory, and about a year ago Mr. Shields built a new septic tank and filter beds. It is planned to use the old tank as a part of the septic system in the future, but at the time of my visit the sewage was flowing only through the newer one. This is 85 ft. long, 20 ft. wide and 8 ft. deep with a central longitudinal partition and 3 concrete baffles. The first two compartments, making up about a third of the tank, bore a thick frozen scum raised by gas pressure 6 in. above the surface of the liquid. At the outlet as it ran off over an aërating weir, the effluent appeared a strong septic sewage still containing a fair amount of suspended matter. The storage period under present conditions appears to be 6 hr. With the addition of the old septic tank, 8 ft. by 17 ft. by 54 ft., it would be increased to 9 hr. Both tanks are of concrete, housed under low brick buildings with gabled roofs.

From the septic tank the sewage flows through an inverted siphon to the filter beds which are located on the further side of a small stream. The beds are eight in number, arranged in two rows with a controlling house in the centre. (Fig. 2.) The four corner beds are each 50 ft. by 110 ft., while the four centre beds are 57.3 ft. by 55 ft., being shortened to provide room for the distribution system. The latter is of the general pattern described above, including a dosing chamber discharged by any one of eight 15-in syphons, each connected with one bed. The rotation of the beds is controlled automatically by a cannon ball device quite similar to that used at Lake Forest.

The filter beds are built up of 12 in. of coarse gravel, 12 in. of fine gravel and 12 in. of coarse sand, and are underdrained by four lines of 4-in. pipe. The carriers are of the usual type, two straight troughs in each bed with 3-in. square holes about 2 ft. apart.

The plant is carefully supervised by the superintendent of the institution, and was working in admirable shape when I saw it. The siphons flush perhaps once every 35 min. in the morning, every 45 min. in the afternoon, and once an hour at night, so that each bed is dosed once in from 4 to 8 hrs. The total area is about 1 acre for the 400 000 gal. treated.

In spite of severe weather in January the dose disappeared in twenty minutes after its application; but at intervals it is necessary to rest a bed for a few days by putting into the cannon ball regulator a chute which shall shut out one of the dosing siphons. The effluent from the plant as I saw it floating into the Menominee Creek was clear and well purified.

It is only rarely that such plants as those at Wauwatosa can be installed in the West, for the use of larger communities, since, even after preliminary septic treatment, the requisite sand area is generally unobtainable. Hence, the newer English types of filters have been frequently adopted; and we find the septic tank and contact filter the most popular of all combinations through Ohio and Iowa. A dozen systems of this type are installed in these states, with an aggregate contributing population of 60 000. Mansfield, O. (20 000), Marshalltown, Ia. (11 000), Delaware, O., and Kenton, O. (each 8 000), are the largest cities in this class.

The disposal system at Mansfield (Pratt, 1905), built by Snow and Barbour, three years ago, is one of the most perfect of this type as well as the largest. The town is a thriving farming and manufacturing centre with a population of 20 000. About half the inhabitants contribute sewage, the total amounting to 1 000 000 gal. per day. The purification works, about three-fourths mile from the centre of the city, and with dwellings not an eighth of a mile away, is as neat as a pin, from its well-kept driveways and embankments to the spotless engine room with a row of potted plants in the window. The sewage flows by gravity to a sludge well from which it is raised by two 7-in. centrifugal pumps to the septic tanks. Both tanks and sludge well are ventilated by connection with the stack from a Dixon crematory in the pumping station which handles the city garbage, amounting to 15 to 20 tons a day.

The septic tank is an arched concrete chamber covered by an artificial mound, its presence being indicated only by the manhole covers. It is built in four compartments, each 50 ft. by 100 ft. and 7 ft. deep with a total capacity for the four of 1 000 000 gal. The sewage flows now through all in parallel, the period of septic action being twenty-four hours. In the three years of their operation these tanks have never been cleaned, and the superintendent informed me that not more than 1 in. of sediment and 2 in. of light scum have ever formed. Comparison with some of the tanks descsibed above suggest that perhaps the longer period of septic action has had some share in these excellent results.

From the septic tanks the sewage flows over a series of aërating steps (Fig. 4), and thence to the regulator house situated in the center of a circular group of five contact beds. The automatic dosing device consists of two concentric iron cylinders about 2 ft. in diameter, the outer one stationary and pierced by five ports, one for each bed, the inner one revolving so as to bring its single influent port successively opposite each of these five .points of discharge. A float, regulated by the height of sewage in whichever bed is filling, at a certain height starts the inner cylinder, closes the outlet from the bed next to be filled and opens the outlet of the bed which has stood full since the last revolution. Each of the beds has an area of one-fourth acre and is filled with one-eighth in. to one-half in. cinders to a depth of 5 ft. The period of contact is about 4½ hr. and the rate of treatment 800 000 gal. per acre per day.

At the time of my visit the beds had been out of use for two or three days during the process of cleaning out part of the low level sewer system, as it was feared the silt might damage them. The septic effluent was going straight to the nearby stream. I was informed by the superintendent that this had occurred only once or twice before during the operation of the plant. The surface of the beds seemed in admirable condition and the effluent of the plant, according to the analysis published by Pratt (1905), is generally excellent.

I was somewhat unfortunate in my experience with contact beds during my trip. Of five plants of this type, that at Mansfield was temporarily out of operation on account of what seem to me quite legitimate reasons. In two others the automatic dosing devices were so frozen up that the beds were not being dosed at all; and a fourth had been entirely abandoned as a nuisance. Only one, that at East Cleveland (Pratt, 1905), was running properly; and this plant is of so peculiar a type that it can hardly be said to operate on the contact plan at all. The flow through three successive rows of slag beds is continuous for a period of several days, air being supplied by forced aëration on the Waring plan; but perhaps this plant may be considered more nearly allied to the contact bed than to any other system.

East Cleveland is a town of 6 000 inhabitants lying near the shore of Lake Erie, just east of the city of Cleveland. The larger part of this population contributes sewage, the total amounting to some 400 000 gal. It is said that this amount is trebled by leakage and surface drainage at certain times of year. At the disposal area the sewage flows first to an open receiving well where a considerable amount of solid matter settles out, the accumulated sludge being pumped out twice a week, mixed with lime and dumped on land near by. The supernatant sewage is pumped from the well to a septic tank, 87 ft. by 24 ft. and 11 ft. deep, covered by a wooden pitched roof. The period of septic action is 10 hr. or less. Pratt (1905) states that after a year's operation about a foot of sludge was taken from this tank. At the time of my visit a heavy cheesy scum, 6 in. in thickness, covered the whole tank and the effluent was markedly turbid. It may be that the period of septic action is too short or that the storm water brings in material not easy to handle; but certainly this tank seems much less successful than others. No problem in sewage disposal is more puzzling than the question why one septic tank succeeds and another fails. Mr. Alvord (1902) strongly maintains that tanks which are too large as well as tanks which are too small tend to fill up, and considers 4 to 8 hr. a proper fermentation period. Shields (1904), on the other hand, recommends that septic tanks should have a capacity of not less than three-fourths of the daily flow.

Certain English experiments seem to indicate that a variation from 12 to 48 hr. makes little difference. It is *a priori* difficult to understand why long periods of septic action should increase sludge deposits. If flow is so rapid that solid particles have not time to settle out or if accumulation of sludge goes on faster than its dissolution, bad results may follow. But with slow flows the processes of liquefaction should have the best chance to do their maximum work, and sludge ought not to accumulate; although here the possibility must be recognized of septic changes in the sewage itself which may be inimical to bacterial action in later processes.

From the septic tank the sewage at East Cleveland flows through three sets of beds filled with 2.5 ft. of coarse slag, of egg-coal size, passing downward through the first, upward through the second and downward through the third. Air is forced into the spaces under each bed by aërators shown in the figure. (Fig. 5.) With the aid of this aëration it was hoped that some of the organic matter could be nitrified and the rest strained out by the slag and finally oxidized by allowing the beds to stand empty for a period at frequent intervals. At present each filter is run for three days and then rested for the same period. The plant is said to give good results in summer, but at the time of my visit it was noticeably offensive in odor, and the effluent was turbid and imperfectly purified. The use of forced aëration seems a doubtful expedient in sewage purification when one considers the large amount of oxygen consumed by sewage in a trickling filter, for example, and the impossibility of supplying such an amount by any practicable mechanical system. The use of the beds for continuous three-day periods also seems unwise. The total filter area of half an acre, if laid out in contact beds somewhat deeper than those now in use and operated in the usual manner, should be able easily to handle the flow of 400 000 gal. daily.

A short distance north of the East Cleveland plant a smaller contact system is installed at the Lake Shore & Michigan Southern Railroad Car Shops in the thickly settled portion of the village of Collinwood (Pratt, 1905). The sewage of 500 operatives flows to a pump well from which it is automatically raised at intervals by a pump driven by compressed air and discharged into two septic tanks, each 21 ft. by 10 ft. by 9 ft. deep, with a capacity of 25 000 gal. When the sewage in the septic tanks reaches a height of 8 ft. they are supposed automatically to discharge the upper 2.5 ft. into four contact beds, concrete basins, each 15 ft. by 29 ft., filled with 5 ft. of 2-in. limestone. On filling, the beds discharge through siphons. The plant is a neat and compact structure with brick walls and plank covering and is supposed to operate entirely without supervision. At the time of my visit all the automatic devices were frozen, the pump was not working, the septic tank contained a thin but foul stagnant liquor and the sewage was apparently flowing off through a by-pass. Such must infallibly prove the fate of automatic devices if their automaticity is construed literally and they are left entirely without supervision.

The fourth contact filter which I visited was at Glencoe, Ill., a suburb of Chicago lying on the northern lake shore between Highland Park and Evanston. It has a population of 1 500, about two-thirds contributing sewage to the system. The Cameron Septic Tank Co. installed a plant some three years ago consisting of a septic tank and double contact beds. Like that at Lake Forest it is located on the shore of the lake and hidden from the town by a high bluff, but in general appearance the plant is sufficiently attractive to be displayed rather than hidden. It consists of a covered concrete tank some 80 ft. long and 10 ft. wide, a set of four primary contact beds with a combined area of about 1 200 sq. ft. and a similar battery of secondary contact beds at a level about 4 ft. lower. On the lower beds are two neat brick regulator houses which contain a complex arrangement of floats and cranks for the automatic control of the beds. (Fig. 6.) The material in the beds is said to be slag, but on the half frozen surface there seemed to be a considerable admixture of rather fine gravel and cinders. According to the City Clerk, the plant worked well for a time, but gradually became a nuisance to the neighborhood, being offensive all through 1904. Last fall the beds became so clogged as to overflow continuously and the plant was abandoned, the sewage being discharged directly into the lake.

I am inclined to think that the conditions in these last two plants are due to difficulties inherent in the contact system of sewage purification as applied to small plants. The process is a complex one involving successive aërobic and anaërobic fermentations which must be delicately adjusted. With the lack of supervision which is almost inevitable in a small disposal system, automatic devices will fail and filters will be thrown out of operation or overdosed so as to cause clogging. The slow sand filter and the trickling filter, being simpler in theory and easier of regulation in practice, are much better fitted for installations liable to be left to themselves for days and weeks at a time.

A plant with a sufficient excess of capacity may, of course, give fair results even when neglected; and a good example of this is furnished by the system at Westerville, O. This village, a few miles northwest of Columbus, has 1 500 inhabitants, but not more than 100 persons are connected. The daily flow is from 20 000 to 25 000 gal. and includes the waste from a creamery, which introduces a large amount of refractory organic matter from the washings of the cans. The sewage first flows through a pair of septic tanks, each 8 ft. by 26 ft. in area and 8 ft. deep, with a combined capacity of about one day's flow. The tanks are of concrete, covered with planking, and appear to do good work, the sewage as it enters being strong and turbid, the effluent clear and free from suspended matters. On leaving the tank the effluent passes through an aërating chamber in which it flows over three iron discs of successively increasing size, the lowest being 2 ft. 6 in. in diameter. It is then passed through six primary contact beds, each with an effective area of 0.021 acre, containing 3 ft. of screened cinders, one-eighth in. to 1 in. in diameter, and finally through two secondary filters, each 13 ft. sq. at the bottom and 31 ft. sq. at the top, containing 6 ft. of cinders. (Fig. 7.) The primary beds are dosed by two devices, each of which consists of a perforated bowl resting ball-and-socket fashion in an upright influent pipe and overflowing through three trough-like arms to the various beds. At the time of my visit the devices were out of order and the sewage was trickling continuously on four of the beds, forming a pool on the surface 6 ft. in diameter which an abundant growth of Leptomitus shows to be fairly permanent. Pratt (1905) in his description of these beds notes the same conditions. The primary beds should be discharged on the secondary beds by siphons, each one operated by the height of sewage in the adjoining bed. These devices, too, were inoperative and sewage was steadily dribbling on, so that both sets of beds were working like trickling filters, but, of course, with the most incomplete sort of distribution. The pools on the upper filters were somewhat offensive and the odor of the plant was noticeable several hundred feet away. The effluent standing on the secondary beds was much less disagreeable and the final effluent below the plant, clear and odorless. With such a low rate of filtration (200 000 gal. per acre per day on each set of beds), even this neglected system was yielding fair results.

In actual operation the Westerville plant was acting like an imperfect sort of trickling filter; but there are *bona fide* systems of this type in the Western States which are of very special interest. The largest trickling filter, I believe, is the one which handles the sewage of the 20 000 people of Madison. I did not see this, but I found a smaller plant installed at the car-shops of the Allis-Chalmers Co. at West Allis, just out of Milwaukee. This plant, designed by Mr. Shields in 1902 to care for 80 000 gal. of sewage per day from the large factory in which 3 500 men are employed, is located on a hillside behind the works and consists of a concrete septic tank and anaërobic filter covered with a gabled roof and a trickling filter under a second roof and at a lower level. The open septic tank is divided by a central partition into two long tanks, each 10 ft. by 58 ft. and 7.5 ft. deep, the total capacity being 65 000 gal. or 18 hr. flow. Below the tank the sewage is aërated by fall over a weir and some steps and then enters the anaërobic filter, so called, which is practically a second septic tank, 21 ft. by 33 ft. long and 7.5 ft. deep, filled with clinker and cinders in graded layers. After flowing upward through this tank the sewage passes to three 3 ft. by 5 ft. siphon chambers which discharge it on the trickling filter below. This filter is practically a pile of cinders and clinker, varying from 0.25 in. to 0.75 in. in diameter, held together by larger clinkers on the outside, piled with a slight batter. The height of the heap is 7.5 ft. to 8 ft., its superficial area, 30 ft. by 54 ft., and the concrete floor upon which it rests is 40 ft. by 60 ft. Considerable trouble has been experienced from disintegration of the clinkers. In winter, as I saw it, the sides of the filter were closed in by plank walls; but in warm weather the whole is open. (Fig. 8.) The distribution system is very simple, consisting of three 12-in. plank troughs with 4-in. lateral troughs in the bottom of which 0.25-in. slits are cut at a distance of 8 in. apart. Each siphon discharge floods one main trough with its laterals, and the distribution as I saw it appeared satisfactory.

The general design of this plant seems admirable, the only part of it to which I should take serious exception being the anaërobic filter. According to the designer (Shields, 1904) its object is "to produce conditions under which the facultative bacteria can do their work and prepare the effluent for more rapid nitrification in the aërobic filter." An action of this sort is very hypothetical. We have little proof that septic action favors subsequent nitrification aside from the removal of suspended solids and some evidence that if prolonged it may seriously hinder it. Furthermore, filling up a septic tank with stone makes the difficulty of cleaning so serious that the extra straining capacity is dearly bought.

Mr. Shields states that the actual flow of sewage at the plant has been much greater than that for which it was designed, reaching a rate of over 300 000 gal. per 24 hr. for 12 hr. of the day. No trouble has been experienced from freezing, and the trickling filter has been operated at a rate of over 3 000 000 gal. per acre per day, yielding a bright and odorless effluent. It appeared evident, however, on my visit that the applied sewage is of unusual character, being mainly clear wash water from boilers and manufacturing processes with fragments of fecal matter floating in it only here and there. Furthermore, its temperature is raised by the spent steam to 70° and over at times. In the trickling filter house the air was wet and steamy, but without any of the offensive odor of ordinary sewage.

For results of general significance on the applicability of trickling filters we must turn to the Columbus experiments. We are all familiar with the inception of these most important investigations. In the fall of 1903 the city appropriated $1 200 000 for the improvement of its sewerage system and the purification of its sewage, and the authorities were sufficiently farsighted to devote $46 000 of the money to a preliminary study of the methods of disposal best suited to the local conditions. An admirable experiment station was designed and a corps of fourteen experts under the direction of Messrs. Hering and Fuller began work Aug. 16, 1904. It includes a laboratory, one set of open tanks for preliminary treatment and three sets of filters, with a gallery under a frame covering, for each set. (Fig. 10.) The sewage, amounting to some 350 000 gal. per day, is raised by a centrifugal pump to a screen chamber in which it passes through two movable screens of three-eighths-in. diagonal wire mesh. Next it passes to one of the tanks for preliminary treatment. These are seven in number, each 40 ft. by 8 ft. and 8 ft. deep at the upper end and 9 ft. deep at the lower end, built of wood lined with galvanized iron. The first two tanks are called grit chambers, the sewage flowing through in about 1.5 hr., and these tanks are used as a preliminary to all the other processes. The other five tanks are either "plain sedimentation" or septic tanks, in which the sewage remains 8 hr. or more, the difference being that the former are emptied and cleaned whenever septic action begins, while the latter have not so far been cleaned. In the septic tanks periods of 8, 16 and 24 hr. are under comparison.

The sewage after treatment by one of these three preliminary processes (grit chamber, plain sedimentation basin or septic tank) is finally purified by treatment in one or more of thirty-five experimental filters. These are cypress tanks 6 ft. deep; one is 10 ft. in diameter, four 12 ft. 10.75 in. in diameter and thirty 7.5 ft. in diameter. They are all open filters and arranged for the most part in two blocks of two rows each with a covered dosing and sampling gallery between the rows, in which all the engineering details of operation are regulated with the greatest accuracy. Twenty-one are intermittent sand filters, 2 primary and 4 secondary contact beds of broken limestone, 2 coke strainers and 5 trickling filters. With this splendid plant the widest possible series of combinations can be tried, including sand filters, trickling filters and contact beds alone, either of these preceded by plain sedimentation or septic treatment and sand filters preceded by contact or trickling filters.

One of the most striking points about this plant is the considerable amount of solid matter which it has been found necessary to remove. First, the sewage is screened where it is pumped out from the sewer; next it passes through two screens of three-eighths in. mesh in the screen chamber; next it settles for an hour and a half in the grit chambers. All the sewage without exception is purified to this extent before its regular treatment begins. I was told that in the sedimentation tanks 2.5 tons of sludge collected per million gallons of sewage treated, while in the septic tanks only half this amount had accumulated with no surface scum. In the second place I was struck with the marked success of the aërobic processes. Sand filters were operating well at rates well above 500 000 gal.; but the thing that interested me most was to see the trickling filter doing good work under most adverse conditions. These tanks are dosed by a spray from an ingenious sprinkler head designed at the station, and while more than a foot of ice had formed round the edges of the beds the area within reach of the spray was kept free and in good condition by the warmth of the sewage. (Fig. 9.)

The report which we may expect from Mr. G. A. Johnson and his associates at the station sometime next autumn will be awaited with the keenest interest. If, as seems probable, it should recommend one of the newer processes of purification, treatment on trickling beds, for example, it will mark an epoch in American practice. Its greatest significance, however, will lie in the fact that it furnishes a standard for the procedure of other communities in the design of sewage plants. While London and Birmingham and Leeds and Manchester have carried out vast experiments upon this subject, Columbus is the first American municipality to make a careful study of local conditions before the construction of a sewage disposal system. It is to be hoped that in the future this may come to be recognized as the only sensible and economical way to attack the question. There are local conditions which make the treatment of each sewage more or less a special problem. In small plants slight differences may be ignored; but no large city should install a purification system without just such an investigation as that in which Columbus has taken the lead.

Such special studies will not only throw light on purely local problems, but must add to our general knowledge of the underlying principles of sewage disposal. Each case has indeed peculiarities of its own; but certain fundamental laws may be formulated which will materially simplify the solution of the individual problem. Thus we now know that chemical precipitation is only in exceptional cases a satisfactory process for preliminary treatment. There are numerous similar important questions still unanswered. We know that sufficient straining and settling to remove paper and garbage, gravel and silt, is always desirable. After this has been accomplished, is it generally of advantage to remove any portion of the suspended solids by fine strainers or by septic treatment, or can all the organic matter be oxidized without the production of putrescible sludge which more or less attends all anaërobic processes? When American sewage is treated in the septic tank what causes the marked variation in the results obtained? Are periods of septic action of less than twelve hours desirable? For subsequent treatment, what are the comparative merits of the contact and the trickling filter? If the trickling filter be used, what is the cheapest system for securing adequate distribution? With intermittent filters, how rapid a rate can be attained under practical conditions, and by what frequency of dosing? These are some of the general questions which press for settlement and whose solution in one set of experiments will be of value, when corrected for local differences, in every other case.

Besides the study of local conditions and the formulation of general principles of engineering practice, we need a third class of data, of a more theoretical character. The processes of sewage purification are chemical changes carried out, as we now believe, by the activity of the bacteria. Sewage treatment is undertaken in order to remove putrescible organic matter, and its efficiency must be measured by chemical tests which shall record the amount and condition of the carbonaceous and nitrogenous material. We need, therefore, more detailed studies on the methods and the interpretation of chemical analysis. As the end of the process is chemical, and its success is measured by chemical methods, so the agents which carry it out are the bacteria, and the conditions which favor or retard it must be determined by bacteriological investigations. Such researches in pure chemistry and bacteriology as are being carried out at Worcester by Prof. L. P. Kinnicutt, at Lawrence by Messrs. H. W. Clark and S. D. Gage, and at Columbus by Mr. W. R. Copeland, must furnish the data which shall lead to the practical development of the art of sewage purification in the future.

In the sewage of the South Metropolitan District of Boston there is discharged in one year 1 500 000 kg. of nitrogen in the form of free ammonia, and 500 000 kg. more as albuminoid ammonia. To convert such vast amounts of material into an innocuous form is a problem in industrial chemistry, of no mean magnitude. It cannot be solved by rule of thumb methods. Theoretical studies, local investigations, expert construction and intelligent supervision are required satisfactorily to meet it.

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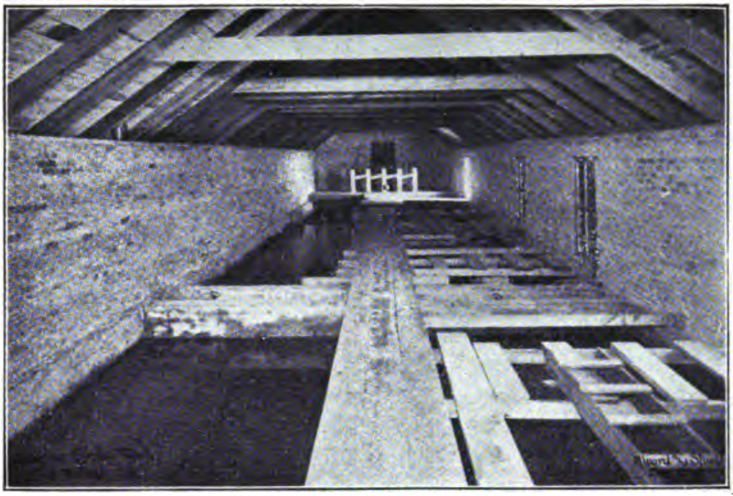

FIG. 1. INTERIOR OF SEPTIC TANK AT LAKE FOREST. IN FOREGROUND LATERAL TROUGH FOR COMBINING VARIOUS COMPARTMENTS. IN BACKGROUND AUTOMATIC DIVERSION CHAMBER.
(After Alvord.)

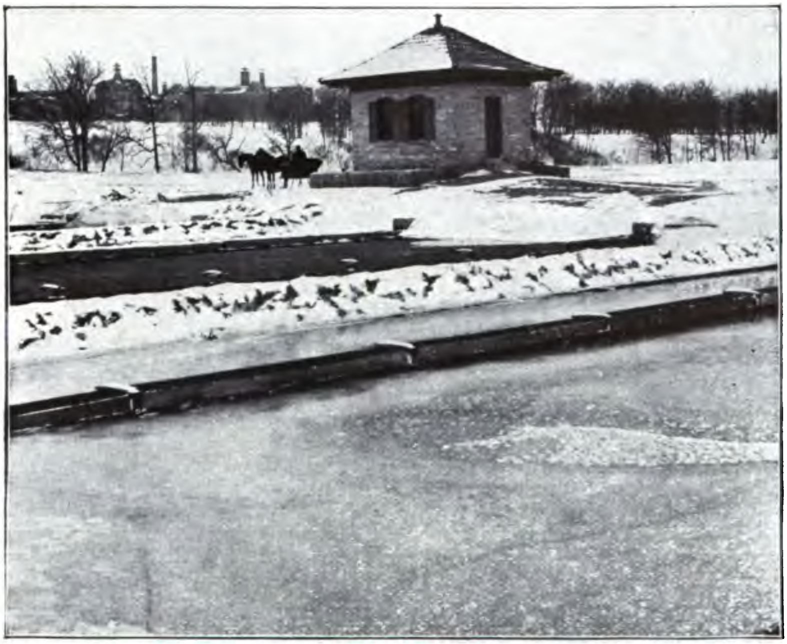

FIG. 2. SAND BEDS AND REGULATOR HOUSE. WAUWATOSA COUNTY INSTITUTIONS.

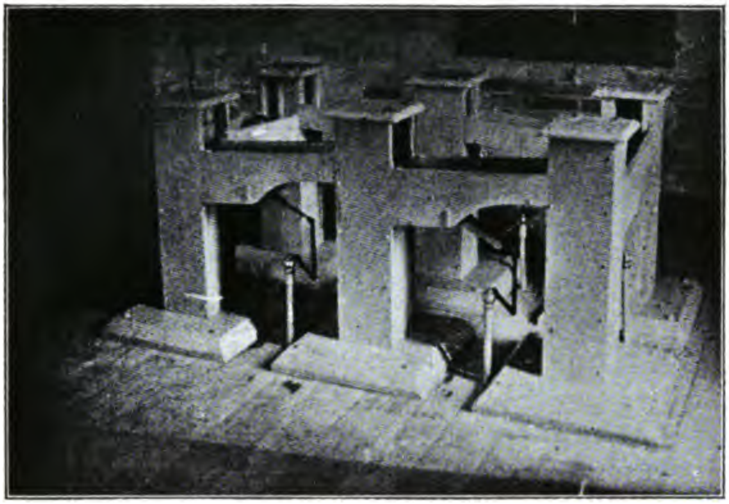

FIG. 3. AUTOMATIC BALL-CONTROLLED DEVICE OPERATING SIX INTERMITTENT FILTRATION BEDS AT WAUWATOSA, WIS. VIEW TAKEN FOUR MINUTES AFTER DISCHARGE IN DIVERSION CHAMBER. DOSE, 6 000 GAL.
(After Alvord)

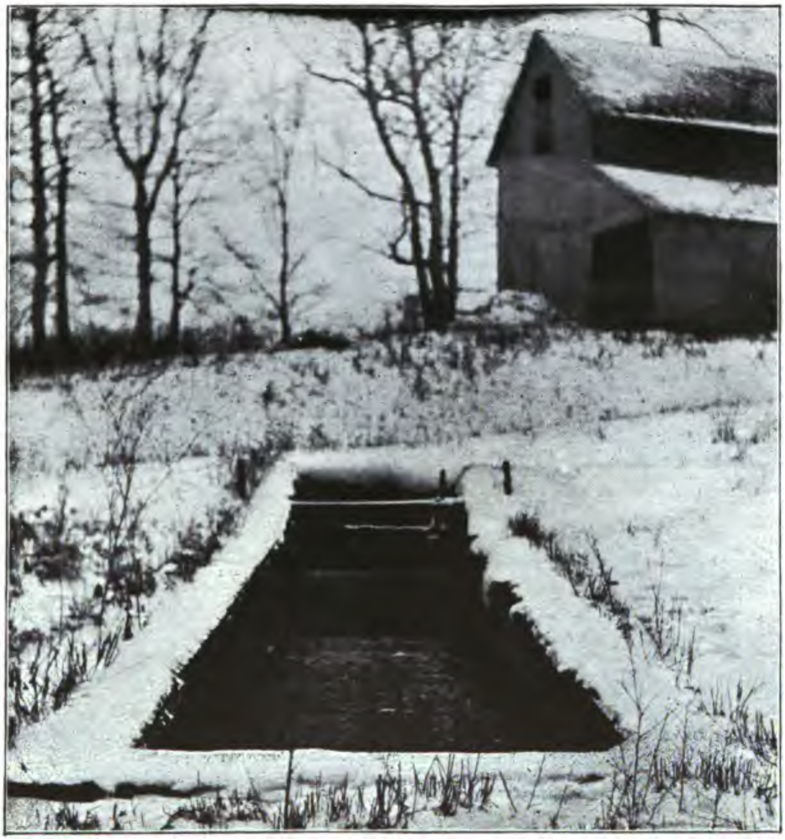

FIG. 4. MANSFIELD AERATING DEVICE

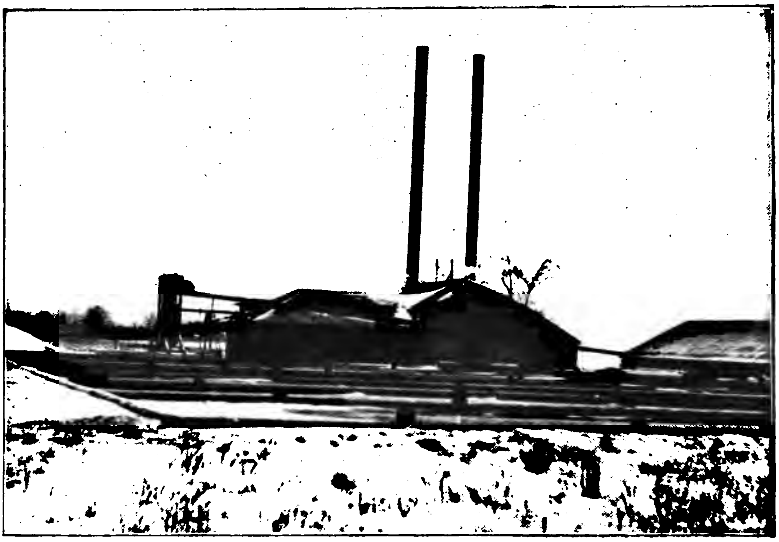

Fig. 5. East Cleveland Pumping Station, with Runway for Sludge from Well, Septic Tank House (on Right), and Filters of Stone with Aerating Devices.

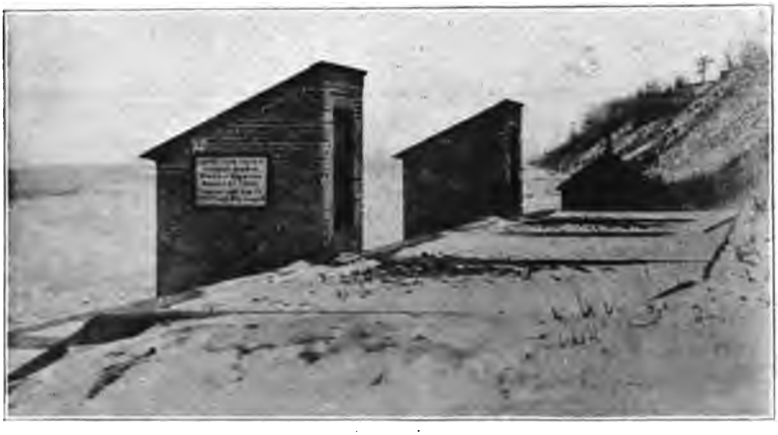

Fig. 6. First and Second Contact Beds and Regulator Houses at Glencoe.

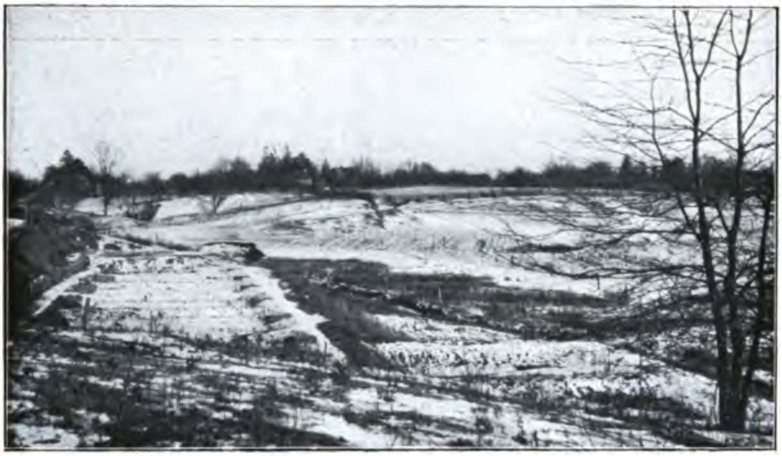

FIG. 7. FIRST AND SECOND CONTACT BEDS, WITH SEPTIC TANK IN BACKGROUND AT LEFT, AT WESTERVILLE.

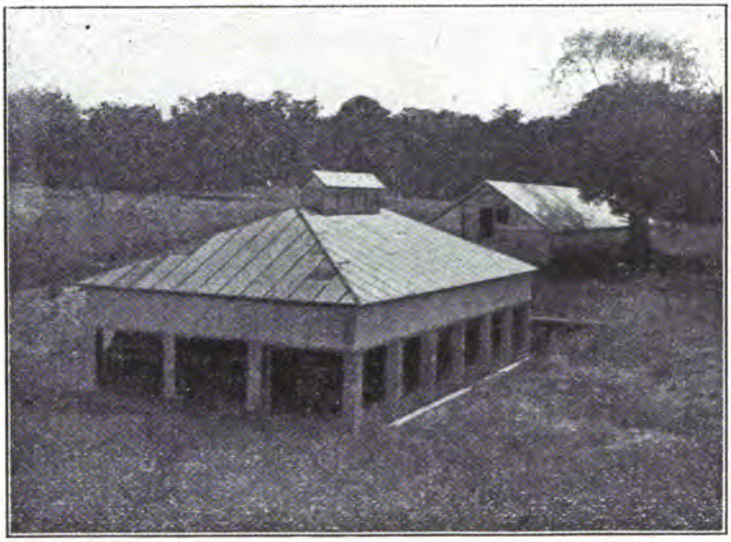

FIG. 8. WEST ALLIS AËROBIC FILTER.
(After Shields.)

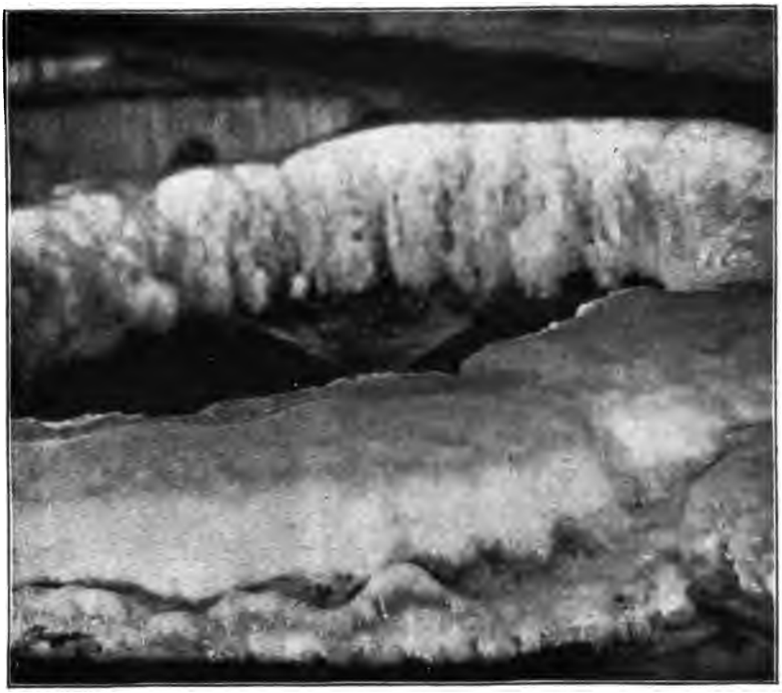

Fig. 9. Columbus Testing Station. Sprinkling Filter.

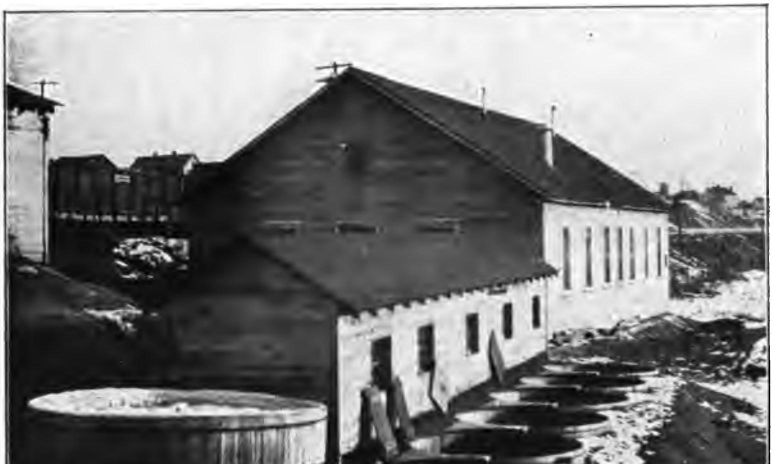

Fig. 10. Columbus Testing Station. Filter House with Laboratory Beyond

ON THE PRESENT RELATIVE RESPONSIBILITY OF PUBLIC WATER SUPPLIES AND OTHER FACTORS FOR THE CAUSATION OF TYPHOID FEVER.

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[*Read November 9, 1905.*]

In a paper read before this Association in 1901, the rise and progress of water-supply sanitation in the nineteenth century was traced with some care. (Sedgwick, 1901.) It was then shown that the responsibility of public water supplies as sources of typhoid fever was first made conspicuous by the epidemics at Lausen, Switzerland, in 1872 (Hägler, 1873), and at Caterham, England, in 1879 (Thorne Thorne, 1880). In this country evidence of the same character was not long lacking; for in 1885 the thriving mining town of Plymouth, Pa., suffered one of the most disastrous water epidemics of which we have even yet any record. (Taylor, 1886.) The great epidemics at Lowell and Lawrence in 1890–91 added new emphasis to the previous lessons (Sedgwick, 1893, *a*); but nevertheless a majority of the largest cities of the United States have continued almost up to the present day to drink water more or less infected with typhoid fever. In the period 1898–1903, there were nineteen cities in the United States of over 200 000 population. Twelve of the nineteen were furnished with public water supplies drawn unpurified from polluted rivers or lakes. The typhoid death-rates in these cities per 100 000 population were as follows (Fuller, Ferguson, and Jeup, 1904):

Pittsburgh	122
Washington	66
Louisville	60
Cleveland	51
Philadelphia	51
Cincinnati	45
Minneapolis	42

Chicago	31
St. Louis	31
Buffalo	29
Detroit	18
Milwaukee	18

For the other seven cities not having supplies drawn from grossly polluted sources, the corresponding rates were as follows:

New Orleans	49
Baltimore	35
San Francisco	31
Boston	26
Jersey City	22
Newark	21
New York	19

There are causes other than the public water supply for the high typhoid death-rates in New Orleans and perhaps in Baltimore. Where no such factors are operative the cities with reasonably pure water supplies exhibit typhoid rates ranging from 20 to 30; 25 would be a fair average figure for American cities of this class. The excess over 25 deaths per 100 000 in the case of Pittsburg, Washington, Louisville, Philadelphia, Cincinnati, and Minneapolis is unquestionably the tax paid by those municipalities for their polluted water supplies. In the first five cities alone this needless waste amounts to 1 200 lives per annum.

And yet great progress has been made in the right direction. The replacement of water derived directly from polluted streams, by filtered or well-stored supplies, goes on with increasing rapidity. Jersey City, for example, where the typhoid death-rate ranged from 52 to 94 between 1890 and 1896, in the latter year abandoned the Passaic River at a point where it was heavily polluted by the sewage of Paterson and Passaic, with the result that the rates for the four years immediately succeeding fell to 21, 36, 15, and 21. Albany effected an equally striking reduction in its typhoid death-rate when a municipal filter was introduced in 1899. (Fuller, Ferguson, and Jeup, 1904.) Of the other communities mentioned above, Washington and Louisville have installed filtration plants within the present year. Philadelphia's system is partially installed, and one of the most serious indictments against the one-time bosses of that apparently redeemed city is the charge that the delay in the completion of this sanitary work is responsible for 1 200 deaths from typhoid fever. Pittsburg and Cincinnati, too, have begun the construction of municipal filter plants, and before many more years the large American city which drinks the unpurified water of a stream, or of a lake with unprotected watershed, will be an exception and an anomaly.

Of special interest in this connection are the statistics of the state of Massachusetts, where the supervision of the public water supplies has been more thoroughly carried out than in any other American commonwealth. In the period 1886–90, the typhoid death-rate for Boston was 39 per 100 000, and for Newton, with an excellent ground-water supply, was 40. The rate for all the cities of the state taken collectively was somewhat higher (46), and the two large cities of Lowell and Lawrence, using the polluted water of the Merrimack River, had each a rate of 112. As later events showed, two-thirds of the typhoid fever in Lowell and Lawrence was caused by water, and this excess, of course, materially raised the rate for the total urban population of the state.

Between 1891 and 1895 the unpurified river-water supplies of Lowell and Lawrence were abandoned, and for the period 1896–1900 their rates fell to 25 and 24 respectively. In at least one of these communities, Lowell, the present water supply, from a series of driven wells, is absolutely protected from infection. In Newton with a rate of 20 and in Woburn with a rate of 13, the conditions are similar. Gloucester, Pittsfield, and North Adams, with rates of 16, 25, and 39 respectively, possess surface supplies of unexceptionable quality from uninhabited watersheds, probably as free from pollution as such waters can often be.

The North Adams typhoid rate may be regarded as due to certain exceptional conditions. We may, however, consider the other five communities as typical of most of the cities of the state, differing only in the fact that our knowledge of the purity of their water supplies is more certain than in other cases. In these five cities we find typhoid rates of 13, 16, 20, 25, and 25. We are confident that these rates are not raised by pollution of the public water supplies and that the influence of private well water upon them is negligible. It therefore follows that typhoid deaths ranging from 15 to 25 per 100 000 are due in these cities to causes other than polluted water; and it is probably fair to assume that at present in similar American communities about this amount of typhoid fever may be expected to occur without its intervention. When we find that the typhoid rate for the whole of Massachusetts in 1896–1900 was only 24, in 1901 only 19, and in 1902 only 22, it seems evident that in this state at least public water supplies are not factors of paramount importance. Eternal vigilance is, of course, the only price of freedom from water-borne typhoid. Particularly in the case of unfiltered surface supplies, such as are common in New England, danger must always be recognized as possible. The 450 cases of typhoid fever at New Haven in 1901 (Smith, 1902) were caused by temporary pollution on a watershed quite as good as that of many a supply in Massachusetts. So great is the danger of such a mishap that as the country becomes more densely populated it must eventually be recognized that no surface water is safe for drinking without purification. Even with filtered supplies only careful and constant supervision will insure safety. Witness the 1 270 cases of typhoid fever at Butler, Pa., in 1903, due to almost criminal carelessness in the operation of the filter plant of the local water company. (Soper, 1903.) The responsibility which rests upon water-works officials still remains, and must always remain, heavy; but, broadly speaking, when this responsibility is well discharged, we may say with confidence, in the light of the expert knowledge at our disposal, that public water supplies play an insignificant part in the causation of typhoid fever in New England.

It must also be remembered that our requirements as to the purity of our supplies have all along been steadily rising and that a far higher degree of purity is to-day demanded, and rightly demanded, in water supplies than was formerly expected or possible. The extraordinary demonstration furnished by the experience of the city of Lawrence with filtered water, in which it has been shown by Mr. Hiram F. Mills and by Hazen (Hazen, 1905) that the general death-rate has been reduced much more than the typhoid death-rate, can only mean that the germs of other common diseases besides typhoid fever are carried by water, unless, indeed, it turns out in the future, as is possible, that the vital resistance of the people using the water has been increased, as the purity of the water has risen. Either alternative is extremely suggestive for water-works officials, and opens out inviting fields for investigation and research.

With the progress of sanitary reform the relative responsibility of water for typhoid fever necessarily decreases. As recently as 1902, Mr. M. N. Baker wrote, "Not only is typhoid one of the leading causes of death in America, but the greater part of it is conveyed, directly or indirectly, through water." (Baker, 1902.) This is still true in Philadelphia and Pittsburg, but it is not true to day, as we have seen, in Massachusetts. Meanwhile, year by year the relative importance of what we may call the *residual typhoid* becomes greater. It is increasingly necessary that the attention of sanitarians should be directed to that tax of 15 to 25 deaths (which means 150–250 cases) per 100 000 population, which typhoid fever still levies on communities provided with ever so pure a water supply. To what shall we attribute this residuum of the disease, so constantly present in most American cities?

In attacking this problem, which concerns not only the epidemiologist but also the practical water-works official who desires to know just how far the water supply under his care may justly come under suspicion, we must begin by remembering that the extension of an infectious disease is the spread of a microscopic parasite; and that this follows much the same course as the distribution of any higher plant. Wheat comes from the ear and eventually finds its way to a favorable soil where it may sprout. So the seed of typhoid infection originates in the body of the typhoid patient and germinates in the intestinal canal of a susceptible victim. The intermediate steps in the history of the wheat may be various. The wind, or a bird, the hairy coat of an animal, or the hand of man, may carry the grain from the place of its origin to the new soil where it sprouts and multiplies. Equally diverse may be the paths by which the typhoid germ is propagated from person to person. Air, earth, water, milk, fruit, flies, soiled clothing, human beings, may intervene; or the transfer may be so direct as to require no intermediary save the two individuals chiefly concerned.

The more we study the prevalence of typhoid fever, the more it becomes evident that its spread goes on in two ways. The first is that in which infection is distributed by a single common medium to a large number of persons at one time. This is characterized by the sickening simultaneously, or at least within a period of a fortnight, of a number of persons who have, perhaps, partaken of some common article of food. Such an explosive outbreak is what the public generally means by an epidemic. Sometimes, on the other hand, we find an undue prevalence of typhoid fever without such coincidence in time and, therefore, of exciting cause. An excessive number of cases of the disease occur which cannot be connected by any common epidemiological bond, but follow each other in a slow succession of scattered or sporadic cases, or in that closer association as to locality to which the older sanitarians applied the word "endemic." As this word is outworn, because by custom associated with the idea of some mysterious but wholly intangible quality inherent in a definite soil or region, the term *prosodemic* has been suggested by one of us for this form of disease "which progresses gradually from person to person by routes which, whether direct or indirect, are often different for each individual case," the term *epidemic* being restricted to "that special case in which circumstances permit the transfer of infection to a large number of persons through the same medium, and at approximately the same time" (Winslow, 1901).

True epidemic typhoid, in the sense in which we have thus defined the word, is generally easy to trace back to its exciting cause. The coincidence of cases fixes the date of infection with approximate accuracy, and the scope of inquiry is at once narrowed down to those vehicles of infection to which all the sufferers have been jointly exposed. Furthermore there are comparatively few methods by which typhoid infection is likely to be transmitted to a large number of persons at the same time. The vast majority of recorded epidemics have been traced with reasonable certainty to one of three vehicles, water, milk, or shellfish. Of these water is by far the most important.

The residual typhoid which still afflicts American cities and large towns, even after they have acquired good water supplies, is undoubtedly due partly to occasional epidemics in which the vehicle is some material other than water,—such as small milk epidemics, shellfish epidemics, celery epidemics, and the like,—even where outbreaks of notable size, in which the infection of a large number of persons can be traced to a common source, are absent. Outbreaks due to milk, although considerable, account, however, for but an insignificant proportion of the total and constant annual mortality; and epidemics distinctly traced to shellfish and raw vegetables have been still more exceptional.

Most of the typhoid cases which occur to-day in Massachusetts and in other communities provided with reasonably good water supplies, are of the sort we have designated as "prosodemic." They are transmitted from person to person by routes which differ in individual cases. The methods by which inspection spreads are almost infinite in number. The chain begins with excreta and ends usually with food; but the intermediate links may be few or many. The fingers of unprofessional attendants upon typhoid patients, or of the patients themselves during the early stages of the disease, and flies, which so often pass freely from infected privies to adjacent larders, suggest themselves as ready vehicles. Sometimes the route is so direct tnat typhoid fever, under uncleanly conditions, becomes for all practical purposes a contagious disease. Sometimes it is so roundabout as to baffle any attempt to trace it.

The devious and obscure course of prosodemic typhoid is no new discovery. It has never been shown more clearly than by Dr. William Budd in his famous monograph published in 1873. (Budd, 1873.) The little village of North Tawton in England suffered a severe outbreak of this character in 1839, over eighty cases occurring between June and November of that year, following each other slowly, several members of a family taking the disease in almost every house in which it appeared. Three infected persons left the place during this summer, and each one formed a new focus for the spread of fever in a region hitherto free from it. In the first case the two children of the sufferer succumbed to the infection; in the second case a friend who acted as nurse took the disease and in turn transmitted it to his two children and his brother; the third of the visitors left North Tawton to stay with a brother at another hamlet seven miles away; the brother's wife, the brother himself, two farm hands, a friend who had come to take charge of the house, another farm hand, two servants, and the daughter of the original visitor successively developed typhoid fever. Evidence of the direct transmission of the disease could scarcely be more conclusive.

In this country the outbreak at Bondsville, Mass., where one hundred cases occurred among the mill operatives in the summer of 1892 (Sedgwick, 1893, *b*), and that of Newport, R. I., in 1900, in which some forty cases, apparently caused by an infected well, were followed by double that number of secondary cases (Winslow, 1901), furnish more recent examples of the same phenomena. In each of these instances the slow succession of cases and the bond of physical association between the victims gave evidence of the prosodemic character of the disease.

There can be little doubt that the emphasis on water and milk epidemics, which produce a striking effect upon the public mind from the number and coincidence of the resulting cases, has led to a general neglect of the less obvious but equally grave danger involved in the spread of prosodemic typhoid. Even the well-water theory may be overworked, for long ago Dr. Rolleston remarked: "And I would add that certain observations which I made recently in a fever-stricken village . . . have induced me to think that of the two recognized foci for infection [in typhoid fever], the bespattered privy and the contaminated well, the former may be the one which is more commonly at work." (Rolleston, 1869.) The doctrine that typhoid fever is "infectious but not contagious" has slain its thousands. In dirty surroundings, typhoid is essentially a contagious disease. Even among trained attendants, with all the advantages of a hospital environment, the number of secondary cases of typhoid is considerable. Collie has recorded that one hundred cases occurred in the staff of the Asylum Board Hospitals of London from 1892 to 1899. (Collie, 1904.)

In the unsanitary conditions which, to our national disgrace, prevailed in the camps of our volunteer soldiery during the Spanish War, the conditions favorable to the transmission of disease reached a maximum and furnished a striking object lesson in the transmission of prosodemic typhoid. (Reed, Vaughan, and Shakespeare, 1904.) Of 107 973 officers and men in the national encampments during the year 1898, 20 738, or nearly one-fifth, developed typhoid fever, with 1 580 deaths.

The disease was spread in a series of independent company outbreaks affecting over 90 per cent. of the volunteer regiments within eight weeks of their assembly in camp. Infected water played no important part. Flies undoubtedly served as carriers of infection, and it was believed that the virus was disseminated to some extent in the form of dust. The vast majority of the cases, however, were caused by more or less direct transfer of infected material under unsanitary conditions. Of 1 608 cases which were studied in detail, 62 per cent. were definitely connected in place and time with earlier cases. The chief factor controlling the incidence of the disease was the system used for the disposal of excreta. Thus, in the Seventh Army Corps, the First Division, with a water-carriage system, had 1 030 cases of typhoid fever; the Third Division, with regulation pits for disposal, had 1 292 cases; the Second, with the thoroughly unsanitary "tub" system, had 2 693 cases. This history of typhoid in the army is simply the history, on an intensive scale, of all prosodemic typhoid.

One of the most interesting features of the "residual typhoid" (not due to polluted water supplies) is its definite seasonal prevalence. In communities provided with reasonably pure water supplies, the typhoid, or as it was called by the older sanitarians, the "fall fever," follows the curve of seasonal temperature with extraordinary regularity. If the monthly deaths from the disease be plotted and compared with the monthly temperature it will be found that the curves are almost parallel, the typhoid fever rising with the temperature after about two months, an interval representing the incubation period of disease and the time which elapses before death. Where the temperature curve is acute, that of the mortality follows it, whereas in a mild climate, the distribution of the disease is more even. In the southern hemisphere both curves are reversed. We have elsewhere shown that these phenomena are so constant and so universal as to suggest in the strongest manner a direct relation between temperature and typhoid fever; and our theory of this relation is as follows:

"The bacteriology and the etiology of typhoid fever both indicate that its causal agents cannot be abundant in the environment during the colder seasons of the year. The germs of the disease are carried over the winter in the bodies of a few patients and, perhaps, in vaults or other deposits of organic matter where they are protected from the severity of the season. The number of persons who receive infection from the discharge of these winter cases will depend, other things being equal, upon the length of time for which the bacteria cast in the discharges into the environment remain alive and virulent. The length of the period during which the microbes live will depend largely upon the general temperature; as the season grows milder, more and more of each crop of germs sent at random into the outer world will survive long enough to gain entry into a human being and bear fruit. The process will be cumulative. Each case will cause more secondary cases; and each of the latter will have a still more extensive opportunity for widespread damage. In our opinion the most reasonable explanation of the seasonal variations of typhoid fever is a direct effect of temperature upon the persistence in nature of germs which proceed from previous victims of the disease." (Sedgwick and Winslow, 1902.)

In cities having polluted water supplies there was an interesting departure from the normal seasonal distribution of typhoid. We found the normal maximum in September or October; but in some cases there were also secondary maxima in the fall and spring as shown in the curves for Chicago. These high death-rates in the cooler months were at first puzzling, and such instances have obscured the usual seasonal variations and led some sanitarians to deny the existence of any relation between typhoid fever and temperature. As soon, however, as it appeared that curves of this type were associated with polluted water supplies, their significance became clear. The fall and spring epidemics coincide with the fall rains and the spring thaws, which wash infecting material from vaults on the banks, or through storm overflows, into the water supplies, carrying it fresh and virulent to the consumers below. A seasonal distribution of this sort appears to be characteristic of many communities drinking from unprotected surface waters; and it was found by us in this country in Chicago, Cincinnati, Newark, and Philadelphia. On the other hand the large majority of cities, including Atlanta, Baltimore, Boston, Charleston, Denver, Mobile, Montreal, New Orleans, New York, St. Paul, San Francisco, and the District of Columbia showed a close and constant relation between the temperature and the seasonal prevalence of typhoid fever.

It is obvious that the difficulties of tracing the path by which prosodemic typhoid spreads in the individual case must often be insuperable. In a crowded community there are so many possible modes of transfer in each separate instance that it is generally impossible to demonstrate the chain of infection, as may often be done in an epidemic inflicted on a number of persons at a definite time and by a single common cause. As intermediate vehicles of the disease, we may have soiled clothing, or bedding, or the woodwork of privies, water, milk, celery, lettuce, or fruit. Food, fingers, and flies offer an alliterative summary of the most common agents. The one thing upon which we can fix our attention with certainty is the common point of departure. Every germ of typhoid fever, whatever its subsequent history, originates in the body of a typhoid patient and leaves it in the excreta. Every case of typhoid fever is due to the presence of excreta on food or fingers, or in some other place where excreta should not be. Filth is the fundamental condition for the spread of typhoid fever; cleanliness the universal panacea for its eradication.

Exactly how much responsibility ought to be assigned to each of the individual factors it is not always possible to say, and we need, therefore, to be particularly careful not to jump too hastily to conclusions. As regards flies, for example, we must remember that while these are unquestionably important vehicles in the spread of typhoid fever, the striking fact remains that the time of greatest mortality from typhoid fever in Massachusetts is not such as to justify, offhand, a belief that flies are the principal vehicle of that disease in this state; for, while typhoid mortality reaches its maximum about the middle of September, a fact which demonstrates that the germs are received by the inhabitants in greatest numbers or under most favorable conditions at some time in August, it is generally believed that September is often, if not always, the worst month of flies. On the other hand, the truth may be, of course, that even if flies are more *numerous* in September they are less *active* than in August, and we must therefore be careful not to dogmatize on either side without sufficient evidence. One fact which stands out with especial clearness the longer we study the subject is that in spite of all that may be, and has been, said to the contrary, *typhoid fever is a contagious disease.* Instead of saying, as is often said, that "typhoid fever is infectious, not contagious," we need to say to-day that "typhoid fever is both infectious and contagious"; and, doubtless, it is in part for this very reason that it has been found so difficult to exterminate.

The conclusion of the whole matter is perfectly clear. Dirt and disease go generally hand in hand, and the importance of disinfection as near as possible to the source of discharge becomes more and more obvious every day. It is plainly wasteful as well as dangerous to allow disease germs to escape from their original sources of supply and become distributed in the environment. Extraordinary pains are therefore requisite in order to destroy their dragon's brood at the very outset, and we cannot help feeling that boards of health are here often remiss. Too often boards of health content themselves with routine work; too often they are more careful for their own political lives than for the lives of the people whom they serve. What we greatly need at present in many of our cities and towns is greater *activity* and *aggressiveness* on the parts of boards of health, especially in respect to sanitation as opposed to hygiene, so that disinfection shall be more carefully done, so that polluted wells, which are still frequently in evidence in many of our thriving towns and cities, shall be closed up, and so that privy vaults and other primitive methods of disposal of excreta which are unfortunately too characteristic of American cities and towns, and whose disappearance is a sure index of effective civilization, shall be cleaned up and done away. Meantime, all good citizens should uphold boards of health in all their reasonable activities, and contribute as far as they can towards that enlightened public spirit which shall insist upon a higher standard of cleanliness in all our cities and towns. But even all these things are not enough.

We greatly need an extension of power in our state sanitary authorities so that these shall be not merely advisory and judicial, but shall have, besides the power and duty of investigating and reporting, some measure of *control,* so that when local authorities are neglectful or powerless, a higher authority may step in and protect the lives and health of the people; for local carelessness, neglect, or ignorance may, and often do, entail the widespread injury of states and even nations. In Massachusetts, for example, we ought to have some system of district sanitary or public health inspectors, and some system of centralized authority similar to that which we have in the state medical examiner system, a system which has replaced with so much advantage the antiquated "coroner" system of former days.

This is an old story. Yet as long as conditions remain unimproved it is a story which must again and again be repeated. The authors of this paper presented a communication bearing a similar title before the American Public Health Association at its New Orleans meeting in 1902, with the following conclusions (Sedgwick and Winslow, 1903) : *First*, that in the state of Massachusetts and in some of the larger cities of the United States the public water supplies are now relatively unimportant as vehicles of typhoid fever.

Second, that in cities having pure water supplies the annual curve of typhoid fever mortality closely follows that of annual temperature.

Third, that in urban communities supplied with pure water there still remains a typhoid fever tax of from 15 to 25 deaths per 100 000 population. (To this we now give the name *residual typhoid.*)

Fourth, that this tax is due, not to any peculiar condition of soil, locality, or climate ("endemic" factors), but to incomplete disinfection of typhoid excreta, with subsequent infection of various articles of food and drink. These factors, when acting upon a few or many persons at one time, may cause obvious epidemics, sometimes large, though generally small; but more often the infection in moving from one point to another follows various, and often obscure, routes for different victims, and hence may be described as *prosodemic*.

Fifth, that the only remedies for such prosodemic typhoid are absolutely thorough and universal cleanliness, and especially a thorough disinfection of all excreta.

The same conclusions may serve for the present communication, and we propose to reiterate and proclaim them at convenient intervals until the public is aroused and educated to that cleanliness which is next to godliness, and our national excess of typhoid fever ceases to be a discredit to American civilization.

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THE TOXIC EFFECT OF CERTAIN ACIDS UPON TYPHOID AND COLON BACILLI IN RELATION TO THE DEGREE OF THEIR DISSOCIATION

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THE TOXIC EFFECT OF CERTAIN ACIDS UPON TYPHOID AND COLON BACILLI IN RELATION TO THE DEGREE OF THEIR DISSOCIATION.*

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1. INTRODUCTION.

The researches of the physical chemists, under the leadership of Arrhenius and Nernst, have shown that certain substances in aqueous solution become dissociated or broken up into electrically charged part-molecules (atoms or groups of atoms), which are called ions. The extent to which this occurs varies with different substances and is greatest in the most dilute solutions. With strong acids and bases, and their salts, it is practically complete at a strength of 0.001 normal. With such solutions it is evident that any effect, chemical or physiological, which they exert, must be due to the dissociated ions. The properties of a dilute solution of sodium chloride are the properties of sodium and chlorine ions, and the properties of hydrochloric acid, of hydrogen and chlorine ions. By the comparison of a series of properly selected compounds it is easy to determine the specific influence of each ion. The study of the toxic action of various substances in the light of these facts promises to be of great assistance in the development of a rational theory of disinfection.

The first definite statement of the relation between dissociation and disinfectant power with which we are familiar was made by Dreser. This author (Dreser, 1893), in a study of the pharmacological value of various salts of mercury, found that the double hyposulphite of mercury and potassium was much less poisonous than other compounds containing the same amount of mercury, and explained the phenomenon by the fact that this salt on dissociation does not set free mercury ions, but breaks up into potassium at the cathode and $Hg\ S_4O_6$ at the anode. His experiments were made on yeast cells, frogs, and fishes. In the former case he found it possible to prevent all development in a yeast culture by mercury salts, and

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then by the addition of potassium hyposulphite to permit fermentation without precipitating any of the mercury, simply by the formation of the differently dissociated double salt.

Scheurlen and Spiro (1897) confirmed the conclusions of Dreser as to the correlation between dissociation and disinfectant action among the mercury salts, and extended them to cover certain compounds of iron. At the same time they maintained that in other cases (the ethylchlorid and ethylsulphate of mercury) strong disinfectant action was apparently due, not to free ions, but to the undissociated molecule.

A number of phenomena which had long been empirically familiar in bacteriology found an easy explanation on the electrolytic theory of disinfection. The effect of temperature in increasing the activity of disinfectants, for example, had been pointed out by Koch (1881), and later by Behring (1890) and Heider (1892), and many others. It was at once obvious that this might be due in some cases to the increased dissociation at high temperatures. It would be well worth while today to see how far the increased activity of disinfectant runs quantitatively parallel to its dissociation. Again, Minervini (1898), and other investigators, have shown that various antiseptic agents (carbolic acid, chromic acid, mercuric chloride, and silver nitrate in Minervini's experiments) are much less active in alcoholic than in aqueous solutions. This fact, too, is easily explicable as due to the diminished dissociation in such solvents.

The relation between dissociation and toxicity was put upon a sound quantitative basis by the work of Krönig and Paul, first published in 1896 (Paul and Krönig, 1896), and in fuller detail in the next year (Krönig and Paul, 1897). These authors carried out an elaborate series of experiments on the disinfectant action of various salts, bases, and acids in the light of the new conclusions of physical chemistry. The details of the investigation were arranged with the greatest care in order to secure comparable results. Spores of *Bacillus anthracis* and vegetative cells of *Micrococcus aureus* were used, dried on Bohemian garnets. By using a definite number of garnets of a certain size shaken up with a suspension of an agar culture, after filtering through paper, and carefully drying, it was found possible to expose approximately the same number of cells in each experiment.

The garnets were dried for 12 hours at 7° and exposed in platinum sieves to the action of the disinfectant solution studied. The temperature was kept constant at 18° C. during the experiment, and after the desired time had elapsed the excess of disinfectant was carefully removed by appropriate reagents (neutralization of acids and bases, precipitation of heavy metals with ammonium sulphide, etc.). After thorough rinsing, the garnets were shaken up with water to detach the cells, which were then plated on agar. No attempt was made accurately to fix a killing point by testing a long series of dilutions of each disinfectant, and no exact calculations were made of dissociation. In a general way, however, the number of spores of *B. anthracis* which developed after treatment for a given time varied inversely with the amount of dissociation. Thus in the study of metallic salts it appeared that the activity of various compounds of mercury, silver, copper, and gold was greatest in those actively dissociated, and decreased in those which yield less free metallic ions. Solutions of mercuric chloride and silver nitrate, in alcohol, where no dissociation occurs, showed almost no disinfectant action. Furthermore, the toxic action of a salt having poisonous metallic ions was markedly diminished by the presence of a non-toxic salt of the same acid. This is in accord with physico-chemical theory; in any solution the ratio between the undissociated molecules and the product of free anions and cations is constant, so that the addition of sodium chloride to mercuric chloride keeps the proportion of chlorine ions the same, but replaces a portion of the mercury ions by those of sodium. So it appeared in Krönig and Paul's work that successive additions of sodium chloride to mercuric chloride progressively increased the number of colonies developing after the usual treatment. In the study of different salts of the same metal it was found that the acid radical may also exercise considerable influence on the disinfecting power.

With bases Krönig and Paul found the same general relation to hold, ammonium hydroxid, which is weakly dissociated, being a much less active disinfectant than the corresponding compounds of potassium, sodium, and lithium. The authors noted in a general way a diminution of disinfectant action in the presence of organic compounds. The decrease was most marked with the halogens and oxidizing agents, and less with acids and bases. Disinfectants themselves of organic nature were least affected.

The particular phase of the subject with which we are especially concerned, the disinfectant action of the acids, was not exhaustively treated in this investigation. One series of experiments was made with normal and half-normal solutions, in which it was found that hydrofluoric, nitric, and trichloracetic acids in normal strength killed all the anthrax spores in 120 minutes. Normal chloric, hydrobromic, and hydrochloric acids and half-normal oxalic acid left a few spores alive after eight hours. Normal sulphuric acid was a little less effective, and normal phosphoric, formic, and acetic acids left large numbers of organisms alive after eight hours. Hydrocyanic acid in normal strength showed little action even after 30 hours. The investigators conclude that there is a general relation between the action of the acids and the amount of dissociated hydrogen present; but there appear many exceptions to a strict parallelism. The authors attribute these exceptional effects to the anion or the undissociated molecule, and point out that in more dilute solutions they tend to disappear. Thus, 0.06 normal solutions of hydrochloric, chloric, nitric, and trichloracetic acids showed about the same disinfectant action, apparently due to the presence of an approximately equal amount of dissociated hydrogen.

At a still earlier period a somewhat similar series of investigations to those of Paul and Krönig had been carried out in another field. This was a study of the relation between toxicity and dissociation as measured by the effect of various salts and bases, and a long series of organic and inorganic acids, on the higher plants, by Kahlenberg and True (1896). Their method consisted in determining the maximum strength of solution in which seedlings of *Lupinus albus* could grow. The seedlings were exposed for 15 to 24 hours, and their condition determined by their general appearance and by the growth which had taken place. These plants proved very sensitive to the action of dilute acid, a strength of from 0.00008 to 0.00064 normal killing them in almost every case. It is interesting to note that boric acid was endured in 10 times this strength. In general, the poisonous action ran parallel with the degree of dissociation, but certain of the organic acids showed relations of their own. The authors concluded that "in the case of plants the toxic action of solutions of electrolytes, when dissociation is practically complete, is due to the action of the ions present. When dissociation is not complete, the undissociated part of the electrolyte may also exert a toxic effect." Heald (1896) extended the work of Kahlenberg and True to the seedlings of three other flowering plants, and reached the same general conclusions. All these authors pointed out clearly that the effect of the common mineral acids is due to hydrogen alone, since their anions have almost no strong toxic action when neutral salts are used.

The next work along these general lines was carried out in another field of botany by Stevens (1898), at the University of Chicago, the measure of viability used being the germination of fungus spores. A study had been made by Wüthrich (1892), at a much earlier date on the toxicity of metallic salts and acids for the spores of fungi; and Maillard (1898 and 1899) at about the same time reported experiments on the inhibition of the growth of *Penicillium* by copper salts. In Stevens' experiments the spores were inoculated into hanging-drop preparations of the solutions tested, and examined for development after 24 hours. The five organisms used exhibited marked differences in their susceptibility, although all were much less affected than the phanerogamous seedlings, requiring a strength of 0.01–0.02 normal acid to inhibit germination. The relative toxic effect of various substances was not unlike that observed by Heald and Kahlenberg and True. Mercuric chlorid and various copper salts proved most fatal, the acids and cyanides being less active. By the comparison of various substances it appeared that of the anions, CN, CrO_4, Cr_2O_7, and OH are poisonous, and of the cations, Hg, Cu, and H, while the halogens and SO_4 in dilute solutions exert no influence.

A still more exhaustive study of the effect of toxic agents upon the fungi was made by Clark in the next year (Clark, 1899). This investigator followed the same general method as that of Stevens, exposing spores in hanging-drop cultures to the activity of the agents to be tested. The cultures were divided into four classes: those which grew normally, those which showed irregular or retarded growth, those which failed to develop in the medium tested, but grew after transfer to fresh beef infusion, and those which entirely succumbed to the action of the toxic substances. The wide difference between the concentration of acid producing, respectively, injury, inhibition, and death was one of the most interesting results of these experiments. As in Stevens' work, it was apparent that the fungi are extremely resistant to disinfectants, and it was necessary to use somewhat concentrated solutions, from 0.008 to 0.287 normal acid, for killing. It is perhaps partly for this reason that, as the author says, "in this study no new evidence has been adduced supporting the theory that the chemical activities of a substance are due wholly or chiefly to the ionized portion." On the other hand, it was held that "in the case of several acids, ionization lessens the chemical activities toward the substances involved in the life-processes of the plant." This conclusion is based on calculations of the specific toxicity of each ion and molecule, obtained by comparing the effects of different compounds varying from each other in one element or group. Thus, hydrochloric acid in the solutions used was over 90 per cent dissociated and since experiments with the similarly dissociated chloride of potassium showed this salt to be practically non-toxic, it is evident that its action was due to the combined effect of the hydrogen ion and the undissociated molecule. Nitric acid, dissociated in the same proportion was much more toxic. Since hydrogen ions are equal in the two cases and since the NO_3 ion is harmless, as shown by experiments with neutral salts, the increased effect must be due to the undissociated part of the molecule of nitric acid. Clark calculates that the toxic value of one molecule of undissociated HNO_3 is 7.7 times that of an ion of hydrogen, so that the acid actually loses nearly seven-eighths of its disinfectant power by becoming ionized.

The effect of sulphuric acid was about the same as that of hydrochloric; since it is less dissociated, the author attributes an appreciable influence to the anion, HSO_4. Acetic acid, at the strength used, is only 2 per cent dissociated, so that its high toxic effect is due to the un-ionized molecule.

The results obtained in this series of experiments with hydrocyanic acid are also interesting. Krönig and Paul (1897) found this acid almost without effect on anthrax spores, while Kahlenberg and True (1896), on the other hand, record very strong toxic action on the seedlings of higher plants. In Clark's experiments it proved far more fatal than any other acid, being 70 times as active as hydrochloric. The molecule at the concentrations used is probably only slightly dissociated.

In some ways the most important work upon this subject was the very careful study made by Bial, of the antiseptic action of the hydrogen ion of dilute acids upon yeast. He first became interested in the problem from a consideration of the causes which allow production of gas in the stomach, and carried out his earliest experiments by observing the gas formation in yeast cultures in the presence of various substances present in the normal gastric juice. This series of studies (Bial, 1897) showed that the presence of albuminoid substances or of sodium chloride effected a marked restriction of the antiseptic action of hydrochloric acid. Bial at this time did not apply physico-chemical theories to the explanation of these phenomena; but in another contribution he made a fuller study of the problem. His later experiments (Bial, 1902) were again made with yeast cells, cultivated in fermentation tubes filled with grape-sugar solution to which various amounts of acid had been added; the antiseptic action was inversely registered by the amount of gas produced. The advantage of this method is its great delicacy; the fermentative power of the yeast responds to such extremely minute quantities of acid that the ionic effects are not complicated by other actions which appear in stronger solutions. Bial did not make exact calculations of the amount of dissociated hydrogen necessary to inhibit the yeast, but he found that a general relation existed between the ionization and the antiseptic action. The strongly dissociated acids — hydrochloric, sulphuric, nitric, and trichloracetic—entirely stopped the action of the yeast in concentrations of between 0.005 and 0.008 normal. Acids of an intermediate grade—phosphoric, formic, and oxalic—accomplished the same effect when 0.01 normal; while acids still less dissociated—acetic, benzoic, and butyric—stopped all fermentation only when 0.04 to 0.07 normal. The most striking feature of Bial's work was a series of experiments on the diminution of the antiseptic action of acids by the addition of neutral salts whose action is to decrease the dissociation of the acidic hydrogen. A solution of 0.01 normal formic acid and 0.3

normal sodium formate showed active fermentation, as did a solution of 0.0166 normal hydrochloric acid and 0.2 normal sodium chloride. The same phenomenon was observed with oxalates, nitrates, sulphates, and acetates. An exhaustive study in the case of hydrochloric acid showed that, while a certain amount of sodium chloride diminished the toxicity of the acid, a much larger amount actually increased it. Bial attributes this to a catalytic action of chlorine ions, but it seems to us that the facts may be explained more simply by the direct inhibiting effect of the sodium chloride and its ions. Bial found that twice normal sodium chloride without any acid prevented fermentation; and it is quite possible, in dealing with living organisms, that the combined effect of the acid and the chloride would be inhibitory at concentrations which with either acid or base alone might allow fermentation to go on. Bial studied also the effect of hydrochloric acid and sodium chloride in the presence of peptone, and found that the yeast would bear more of the salt than in the presence of acid alone.

The experiments of Paul and Krönig demonstrated clearly that in certain solutions disinfectant action runs parallel with the presence of dissociated ions. The work upon the higher plants and the mold fungi confirmed these results, but showed that in other cases the undissociated molecule is of great importance. Bial's studies brought out clearly the influence of neutral bodies, inorganic salts or proteids, in diminishing disinfectant action by decreasing dissociation.

The problem is, of course, complicated by still other chemical interactions which are more obscure. For example, Scheurlen, (1895), Beckmann (1896), Römer (1898), and Spiro and Bruns (1898) have shown that in the case of phenol and certain other organic disinfectants the addition of sodium chloride greatly increases toxic action. Still another factor which affects disinfectant power has been brought out in recent years by Nägeli (1893), and other observers—the presence of suspended solid particles of neutral character. In the most recent communication upon this subject by True and Oglevee (1905) it was shown that the toxic effect of metallic salts upon *Lupinus* may be entirely counteracted by the presence of finely divided particles of sand, glass, filter paper, coal, starch, or paraffin. On the other hand,the toxic effect of organic disinfectants

—phenol, thymol, and resorcinol—was affected only to a barely appreciable degree. The action when it occurs is explained by the power of suspended particles to remove dissolved substances by a process of adsorption, and the possibility suggests itself that the removal of ions by large organic molecules in true or colloidal solutions may be of an analogous character. Whatever the cause, this phenomenon must prove of far-reaching importance in bacteriology. Such facts as the observed multiplication of bacteria, when water samples are stored in glass bottles, may be the result of a removal of inhibiting substances by the adsorptive action of glass surfaces.

A considerable body of evidence in the field of animal physiology bears out these conclusions obtained from the study of bacteria and other plants. A fairly full summary of this literature may be found in the reviews of Cohen (1903) and Hamburger (1904). The work of Kahlenberg (1898) and other observers, who have shown that the taste of dilute solutions is in many cases due to the specific properties of the dissociated ions, is of interest. Studies which have been frequently cited were made by Loeb (1897 and 1898), and recently reprinted (Loeb, 1905), on the influence of free ions upon frog's muscle. The gastrocnemius muscle absorbs water and increases its weight in the presence of slight traces of acids or alkalis, and Loeb concluded that for the inorganic acids and bases this increase in weight is solely a function of the number of hydrogen and hydroxyl ions in the unit of volume. This sweeping conclusion is hardly borne out by his experiments. With the organic acids there was no relation whatever. Trichloracetic acid, almost entirely dissociated, and lactic acid, with only 11 per cent dissociation, gave practically the same results. With a series of 11 different organic acids of every degree of dissociation, the individual variation in weight-increase, with 0.009 normal solutions, ranged only between 3.9 per cent and 7.2 per cent.

A very significant line of physiological investigation concerns the binding of free ions by organic molecules of large size. In one of the most recent communications on this subject, Stiles and Beers (1905) have shown that the effect of calcium chloride, barium potassium chloride, and sodium nitrite upon plain, cardiac, and striped muscle of the frog, terrapin, and guinea-pig was reduced from one-half to three-fourths in the presence of white of egg, partially dialyzed serum, peptone, or starch. In some cases a combination between the inorganic body and the proteid has been demonstrated by freezing-point determinations, but in other cases particularly with the neutral salts, this has not been shown. As the authors suggest, these experiments point to the existence of "*physiological compounds* which are not demonstrable at all by chemical methods, but only by the reactions of living tissues."

2. OBJECT AND METHODS OF THE PRESENT INVESTIGATION.

The present investigation was begun with the intention of determining the effect of acid wastes in sewage upon the viability of the typhoid bacillus under practical conditions. It soon appeared, however, that the problem was too complex to be attacked in any general way without the preliminary determination of certain of the individual factors involved, under definitely controlled conditions. We have therefore attempted to find the disinfectant power of two mineral acids and two organic acids upon the typhoid bacillus in tap water and in the presence of peptone, and have controlled these experiments by a parallel series with the colon bacillus. The results, besides their specific value as determinations of the reactions of these two organisms to dilute acids, have a certain interest in relation to the general theory of disinfection. In all the experiments reviewed above, except Bial's, the acids used were tested in only a few widely differing strengths, so that the parallelism between disinfectant action and dissociation was not established with any great exactness. In the work of Krönig and Paul on anthrax spores and the various studies on the mold fungi, it was necessary to use such strong solutions that ionic effects were largely masked by the influence of the undissociated molecule, and in the studies of Kahlenberg and True and Heald on the phanerogams it was evident that with such complex organisms many other factors than the direct effect on protoplasm come into play. There was room, therefore, for a series of experiments on organisms sensitive to very dilute acids, carried out in sufficient detail to show definitely the relations between toxicity and dissociation.

With the view of securing exact quantitative results, we adopted the method of exposure to the acid tested, in a suspension from which samples were directly plated. This process has the obvious defect of permitting a certain amount of the disinfectant to be carried over to the plate, where it may exert an antiseptic action. We have really measured the combined disinfectant action in the suspension and possible antiseptic action in the plate. The action of organic matter in decreasing toxicity, shown by our experiments, must greatly reduce any such action in the plate.

The procedure in each experiment was as follows: A series of bottles, each containing 100 c.c. of sterile water (or peptone solution), was arranged in a row, and to each bottle was added a different amount of standardized acid from a graduated pipette. The amount of water in each bottle was measured at the end of the experiment, in order to obtain the exact strength of the solution. Immediately after the addition of the acid there was added to each bottle 1 c.c. of a fresh aqueous suspension of the bacteria tested. After standing for 40 minutes, lactose agar plates were made in duplicate, from the acidified bottles, and from controls with no acid. Colonies were counted after 24 hours' incubation at 37° C.

Forty minutes was selected, after some preliminary experiments, as the best period of exposure to the acid, since it gave sharper results than a shorter time. In the tests reported in the accompanying tables there was not a variation from the 40 minutes of more than one minute in most of the samples. The series for *B. typhi* in water, with HCl, were also examined after 100 minutes, and after 24 hours. In the sample containing 48 parts per million of sulphuric acid, there was, after 40 minutes, 59.3 per cent removal of *B. typhi;* after 100 minutes, 88.15 per cent removal; after 24 hours, 100 per cent removal. The sample containing 92.9 parts per million of sulphuric acid removed after 40 minutes 92.97 per cent; after 100 minutes, 99.99+ per cent; after 24 hours, 100 per cent. The removal was 100 per cent in all of the samples containing larger amounts of acid after 103 minutes, and in all of the samples after 24 hours.

The temperature factor was of considerable importance, and care was taken to keep conditions uniform. No agar was poured with a temperature greater than 50° C. It was found that a rise in temperature in the presence of the acid was very fatal in its effect on the bacteria.

The typhoid culture used was obtained from the Massachusetts General Hospital, where it had been isolated from the spleen of a clinically typical case of typhoid fever; the colon bacillus was isolated in the laboratories of the Institute, and both gave all characteristic reactions. Twenty-four-hour agar-slant cultures were used in all cases.

The tables have been prepared to show, in the first column, the parts per million of the acid, and in the second column the parts per million of acidic hydrogen or, more accurately, of replaceable hydrogen. The third column shows the strength converted into terms of normality. The percentage dissociation of the acids at each dilution is given in the fourth column, and the actual parts of dissociated hydrogen in the fifth. The last two columns show the initial number of bacteria used as shown by blank controls and the percentage reduction after 40 minutes.

The tables show in general that with increasing quantities of disinfectant the bacterial reduction proceeds rapidly up to a certain point. After 99 per cent of the organisms have been killed, however, it takes a very considerable further increase of acid to produce sterilization. This is a point of very fundamental importance, and one which has been observed in studying the effect of such various agents upon the bacteria, that it deserves special attention. Sedgwick and one of us (Sedgwick and Winslow, 1902) have called attention to the persistence of a few specially resistant individuals when typhoid bacilli are exposed to the action of cold. After 14 days of exposure to freezing temperature 99.8 per cent of the organisms were killed, but after three months a few still survived. Johnson's tables of the reduction of typhoid and colon bacilli by copper salts (Johnson, 1905) show the same phenomenon, although he does not comment upon it specifically. More recently, Frost and Swenson (1906), and Gage and Stoughton (1906), have emphasized this peculiar phenomenon, in connection with resistance to high temperatures. The former authors, working with *B. dysenteriae*, found that "the majority of the cells were killed between 55° and 60°, but that frequently a relatively small number, possibly one individual in a hundred thousand or a million, may persist at much higher temperatures, even 70°." Gage and Stoughton in their conclusions point out that "the great majority of the bacteria in any *B. coli* cultures are destroyed by five minutes' exposure to some temperature between 50° and 60° C. A few individuals, however, in each culture will survive much higher temperatures, in some cases remaining alive after exposure to 90° C. The very close range (about 10° C.) of temperature at which the destruction of the majority of the individual bacteria occurred, as compared with the considerable range (about 35° C.), in the temperatures at which complete sterilization was effected would indicate that the determination of the majority death-point would be of more value in species identification than is the determination of the absolute thermal death-point as at present employed."

Altogether it seems clear that among what are ordinarily considered non-sporing bacteria there exists a small proportion of individuals having specially high resistant powers against unfavorable conditions. The absolute death-point for these resistant forms is difficult to determine accurately on account of their small numbers and the consequent chances that they may be overlooked. We are inclined from our experience to agree with Gage and Stoughton as to the superior value for many purposes of the majority death-point (99 per cent), and we shall lay special stress on this in interpreting our results.

3. THE DISINFECTANT ACTION OF HYDROCHLORIC ACID AND SULPHURIC ACID UPON *B. TYPHI* AND *B. COLI.*

Hydrochloric acid and sulphuric acid were chosen as types for the study of strong mineral acids, and the experiments were carried out as described above. The water used was Boston tap water, containing before sterilization about 40 parts per million of residue, 15 parts of hardness, 0.015 part of free ammonia, and 0.144 part of albuminoid ammonia. The results are shown in Tables 1–4.

The 99 per cent killing-point with the hydrochloric acid is reached at a strength of 0.0077 normal, with 7.49 parts of dissociated hydrogen per million, and the absolute killing-point, as nearly as it can be determined, with a 0.0123 normal solution containing 11.80 parts

TABLE 1.

ACTION OF HYDROCHLORIC ACID ON *B. coli* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
38.1	1.05	0.0010	98.0	1.03	40,000	00.00
77.6	2.13	0.0021	98.0	2.09	“	45.00
104.5	3.32	0.0033	97.5	3.24	“	72.85
149.0	4.08	0.0041	97.3	3.98	“	82.50
178.9	4.90	0.0049	97.2	4.76	“	97.50
281.0	7.71	0.0077	97.0	7.49	“	99.87
298.0	8.17	0.0082	96.5	7.90	90,000	99.96
377.0	10.61	0.0106	96.4	10.24	“	99.99
447.0	12.26	0.0123	96.4	11.80	“	100.00
515.0	.....	......	96.3	....	“	100.00
590.0	.....	......	96.3	....	“	100.00
663.0	.....	......	96.2	....	“	100.00

TABLE 2.

ACTION OF SULPHURIC ACID ON *B. coli* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment.	Percentage Reduction of Bacteria after 40 Min.
45.9	0.94	0.0009	93	0.87	60,000	66.20
46.5	0.95	0.0009	93	0.87	140,000	80.00
111.5	2.28	0.0023	90	2.05	“	81.43
138.3	2.82	0.0028	89	2.51	60,000	86.50
176.6	3.62	0.0036	88	3.18	“	96.25
178.2	3.64	0.0036	88	3.20	140,000	82.14
225.2	4.59	0.0046	86	3.94	60,000	96.25
257.2	5.25	0.0052	85	4.46	“	98.50
311.5	6.36	0.0064	84	5.35	140,000	97.50
375.9	7.68	0.0077	83	6.38	“	98.86
470.0	9.60	0.0096	80	7.68	“	99.92
552.0	11.30	0.0113	79	8.93	“	99.92
630.0	12.90	0.0129	78	10.05	“	99.95
692.5	14.13	0.0141	77	10.90	“	99.95
812.0	16.57	0.0166	76	12.60	“	100.00
910.0	18.57	0.0186	75	13.95	“	100.00

of dissociated hydrogen. With the sulphuric acid the 99 per cent reduction was reached at a strength of 0.0096 normal, with 7.68 parts of dissociated hydrogen, and the 100 per cent reduction at a strength of 0.0166 normal, with 12.6 parts of dissociated hydrogen. These results show a direct relation between disinfectant action and free hydrogen ions. The normal strengths of the killing solutions do not correspond very closely; 0.0077 sulphuric acid failed to do what the same strength of hydrochloric acid did, and 0.0129 and 0.0141 sulphuric acid failed to do what 0.0123 hydrochloric acid did. On the other hand, when we compare dissociated hydrogen, allowing for the greater ionization of the hydrochloric acid, the discrepancies disappear. The same concentrations of dissociated hydrogen, within the limits of accuracy of the experiment, produced respectively the 99 per cent and the 100 per cent reduction in the two acids.

TABLE 3.

ACTION OF HYDROCHLORIC ACID ON *B. typhi* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
38.2	1.00	0.0010	98.2	1.02	7,050	79.20
75.3	2.06	0.0021	97.9	2.02	"	88.10
109.5	3.00	0.0030	97.8	2.94	"	99.30
148.2	4.06	0.0041	97.3	3.95	"	99.86
182.5	5.00	0.0050	97.1	4.85	"	100.00
216.8	5.92	0.0059	....	....	"	100.00
248.0	6.80	0.0068	....	....	"	100.00
275.5	7.54	0.0075	....	....	"	100.00

TABLE 4.

ACTION OF SULPHURIC ACID ON *B. typhi* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1 000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
48.0	0.98	0.0010	93.1	0.91	135,000	59.30
92.9	1.88	0.0019	90.5	1.70	"	92.97
139.4	2.84	0.0028	89.5	2.54	"	99.99
188.9	3.85	0.0038	87.0	3.35	"	96.10
223.0	4.55	0.0045	85.5	3.90	"	100.00

Tables 3 and 4 show that the typhoid bacillus is considerably more sensitive than the colon bacillus in its reaction to an excess of acid. The 99 per cent reduction was reached with hydrochloric acid at a strength of 0.0030 normal and 2.94 parts of dissociated hydrogen, and the 100 per cent reduction with 0.0050 normality and 4.85 parts of dissociated hydrogen. With sulphuric acid the 99 per cent reduction was reached with 0.0028 normality and 2.54 parts of hydrogen, and the 100 per cent reduction with 0.0045 normality and 3.90 parts of hydrogen. The fact that the 0.0038 normal solution of sulphuric acid showed only 96 per cent reduction is one of the abnormalities which unfortunately sometimes occur in bacteriological work. In general, the results show again that the two acids exert the same quantitative effect, although in this case, the solution being weaker and the dissociation of the two acids more nearly the same, the difference between normal strength and concentration of dissociated hydrogen is not clearly shown.

The critical points derived in these tests are brought together in Table 5. They show that the typhoid bacillus is a little less than half as resistant as the colon bacillus to dilute acids, and that the toxicity of these acids depends, not on their normal strength of acid or on the kind of acid used, but on the number of dissociated hydrogen ions. Between 7.4 and 7.7 parts of dissociated hydrogen effects a 99 per cent reduction of the colon bacillus, and between 11.8 and 12.6 parts, a 100 per cent reduction. For the typhoid bacillus the corresponding figures are 2.5–3.0 parts and 3.9–4.9 parts. Since at the dilutions used the hydrochloric acid was over 96 per cent dissociated, its effect must have been almost entirely ionic; and since the sulphuric acid at 75 per cent dissociation showed only the toxicity which would have been expected from its dissociated hydrogen, it appears that in this case too the undissociated molecule exerts no appreciable influence. The anions have been shown to be neutral in the experiments of other observers. It is evident, then, that the toxicity of these acids at high dilution is a function of the dissociated hydrogen.

TABLE 5.

DISINFECTANT ACTION OF MINERAL ACIDS IN TAP WATER.

	B. coli				*B. typhi*			
	99% Reduction		100% Reduction		99% Reduction		100% Reduction	
	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4
Normality	0.0077	0.0096	0.0123	0.0166	0.0030	0.0028	0.0050	0.0045
Parts per 1,000,000 dissociated hydrogen	7.49	7.68	12.80	12.60	2.94	2.54	4.85	3.90

4. THE DISINFECTANT ACTION OF ACETIC ACID AND BENZOIC ACID UPON *B. TYPHI* AND *B. COLI.*

We next desired to study examples of the incompletely dissociated organic acids. Acetic and benzoic acids were selected as types, and the experiments were carried out as before. The results obtained with benzoic acid are probably somewhat inaccurate on account of the difficulty of securing complete solution. The results are shown in Tables 6–8.

An inspection of these tables shows a marked difference from the results obtained with the mineral acids. With *B. coli* in acetic acid the 99 per cent reduction is reached at a strength of 0.0812 normal, and

TABLE 6.

ACTION OF ACETIC ACID ON *B. coli* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
111.3	1.85	0.0018	....	....	60,000	00.00
333.0	5.54	0.0055	6.40	0.35	"	00.00
552.0	9.18	0.0092	4.50	0.41	"	16.67
732.0	12.20	0.0122	3.50	0.43	"	23.33
1,095.0	18.25	0.0182	3.05	0.56	"	38.33
1,386.0	23.20	0.0232	2.75	0.64	"	51.67
1.825.0	30.41	0.0304	2.45	0.75	"	55.00
2,260.0	37.70	0.0377	2.20	0.83	"	56.67
3,081 0	51.40	0.0514	1.90	0.98	"	58.33
3,698.0	61.70	0.0617	1.70	1.05	"	63.33
4,800.0	80.20	0.0802	1.50	1.20	"	91.00
4,875.0	81.25	0.0812	1.50	1.21	90,000	99.99
5,610.0	93.50	0.0935	1.35	1.26	"	100.00

TABLE 7.

ACTION OF BENZOIC ACID ON *B. coli* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
237.9	1.95	0.0019	16.0	0.31	70,000	00.00
337.0	2.76	0.0028	13.6	0.38	"	50.00
406.0	3.33	0.0033	12.5	0.41	"	60.75
675.0	5.54	0.0055	9.3	0.52	"	67.80
1,184.0	9.72	0.0097	7.5	0.73	"	99.99
2,425.0	19.90	0.0199	5.4	1.07	100,000	100.00

TABLE 8.

ACTION OF BENZOIC ACID ON *B. typhi* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
29.23	0.24	0.0002	40.0	0.10	50,000	44.00
140.30	1.15	0.0011	20.3	0.23	"	54.00
243.80	2.00	0.0020	15.4	0.31	"	62.00
333.00	2.73	0.0027	13.6	0.37	"	70.00
427.00	3.52	0.0035	10.4	0.37	"	92.00
689.00	5.75	0.0057	9.8	0.56	"	100.00
1,292.00	10.60	0.0106	7.2	0.76	"	100.00

the 100 per cent reduction at 0.0935 normal. The acid at these strengths is only a little over 1 per cent dissociated, and the amount of dissociated hydrogen present a little over 1.2 parts per million. Since this is only about one-sixth the strength of ionic hydrogen necessary to produce similar results with the mineral acids, it is evident that the toxic action of the acetic acids is due chiefly to the anion or the undissociated molecule, the latter, being so much greater in amount, probably playing the principal part. The same thing is true of benzoic acid. Here the molecule is more highly toxic, producing a 99 per cent reduction at 0.0097 normality and a 100 per cent reduction at 0.0199 normality, with about 1 per cent dissociation. As in the case of the mineral acids *B. typhi* is more sensitive than *B. coli*, showing 100 per cent reduction with benzoic acid at a strength of 0.0057 normal.

It appears, then, that the toxicity of these organic acids is due not mainly to hydrogen ions, but to the action of the undissociated molecule, varying widely, as might be expected, with the acid employed. A comparison of the corresponding toxic normal strength, made in Table 9, shows that benzoic acid is almost as toxic as the mineral acids, the effect being due in one case to the whole molecule, and in the other case to hydrogen ions. Acetic acid, on the other hand, has only 10–20 per cent as high a disinfectant action.

TABLE 9.

TOXICITY OF ORGANIC AND MINERAL ACIDS FOR *B. coli* AND *B. typhi*. STRENGTH IN NORMALITY PRODUCING 99 PER CENT AND 100 PER CENT REDUCTION.

	B. coli		*B. typhi*	
Acid	99% Reduction	100% Reduction	99% Reduction	100% Reduction
Hydrochloric	0.0077	0.0123	0.0030	0.0050
Sulphuric	0.0096	0.0166	0.0028	0.0045
Acetic	0.0812	0.0935	......	......
Benzoic	0.0097	0.0199	......	0.0057

5. THE DIMINISHED TOXICITY OF ACIDS IN THE PRESENCE OF PEPTONE.

Having fixed with some precision the killing-point for the various acids studied, when acting in tap water, we next desired to determine what would occur in the presence of organic matter. A series of experiments was carried out, parallel to those reported above, except that a 1 per cent solution of Witte's peptone was used instead of tap water. The results with the mineral acids, presented in Tables 10–12, showed that the toxicity of the acid is profoundly modified by the presence of organic matter.

TABLE 10.

DISINFECTANT ACTION OF HYDROCHLORIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
1,118	30.62	0.0306	94.8	29.0	90,000	40.00
1,825	50.00	0.0500	94.8	47.5	"	93.35
2,502	69.00	0.0690	93.0	64.2	"	97.97
2,950	80.80	0.0808	92.0	74.4	"	97.74
3,470	95.20	0.0952	91.5	87.5	"	99.98
3,685	97.80	0.0978	91.4	89.4	"	100.00
4,020	110.00	0.1100	....	....	"	100.00

TABLE 11.

DISINFECTANT ACTION OF SULPHURIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c. c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
970	.....	......	....	....	140,000	00.00
1,204	.....	......	....	....	"	00.00
1,405	.....	......	....	....	"	00.00
1,536	31.4	0.0314	70.0	22.0	"	00.00
1,728	35.3	0.0353	68.5	24.2	"	20.00
1,962	40.1	0.0401	67.5	27.1	"	61.43
2,066	40.9	0.0409	67.0	27.4	"	64.29
2,399	48.9	0.0489	65.4	32.0	60,000	76.67
2,639	53.8	0.0538	64.8	24.9	"	79.17
2,912	59.4	0.0594	64.2	38.1	"	91.67
3,065	62.6	0.0626	63.2	30.6	"	93.33
3,258	66.5	0.0665	62.8	41.8	"	94.17
3,450	70.4	0.0700	61.9	43.5	"	98.85
4,610	94.2	0.0942	58.9	55.5	65,000	99.99
5,298	108.1	0.1081	57.0	61.6	"	100.00
6,555	135.2	0.1352	....	....	"	100.00
7,800	159.3	0.1593	....	....	"	100.00

TABLE 12.

DISINFECTANT ACTION OF HYDROCHLORIC ACID ON *B. typhi* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
1,107	30.3	0.0330	94.8	28.7	50,000	99.99
1,740	47.6	0.0476	93.8	44.6	50,000	100.00

In these tables the dissociation values given are those determined for distilled water, and not those which actually obtain in a peptone solution. The amount of dissociated hydrogen required for disinfection, when estimated in this way, is seen to be nearly 10 times as great as in tap water. For comparison the results are brought together in Table 14.

TABLE 13.

DISINFECTANT ACTION OF SULPHURIC ACID ON *B. typhi* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c. c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
819	17.03	0.0170	74.5	12.7	85,000	00.00
960	20.00	0.0200	73.7	14.7	"	17.65
1,104	22.52	0.0225	72.0	16.2	"	17.65
1,139	23.17	0.0232	72.0	16.7	"	34.10
1,288	26.32	0.0265	71.0	18.7	"	61.20
1,453	29.63	0.0296	70.2	20.8	28,000	82.15
1,472	30.03	0.0300	70.1	21.0	85,000	76.45
1,519	31.66	0.0317	69.7	21.6	28,000	89.30
1,587	32.39	0.0324	69.5	22.5	"	89.30
1,612	32.89	0.0329	69.0	22.7	"	100.00
1,678	34.24	0.0342	68.5	23.4	"	97.86
1,879	38.32	0.0383	68.0	26.0	"	100.00
1,994	.....	......	....	....	"	100.00
2,045	.....	......	....	....	"	100.00
2,115	.....	......	....	....	"	100.00
2,119	.....	......	....	....	"	100.00
2,399	.....	......	....	....	"	100.00

TABLE 14.

COMPARATIVE TOXICITY OF MINERAL ACIDS IN DISTILLED WATER AND 1 PER CENT PEPTONE SOLUTION.

(Parts per 1,000,000 of dissociated hydrogen.)

	B. coli				*B. typhi*			
	99% Reduction		100% Reduction		99% Reduction		100% Reduction	
	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4
Distilled water..........	7.49	7.68	11.80	12.60	2.94	2.54	4.85	3.90
1 per cent peptone......	87.5	55.5	89.4	61.6	28.7	....	44.6	22.7

It is evident that in some way the peptone exerts a strong influence in counteracting the toxic effect of the acids. It at first occurred to us that this might be due simply to the fact that peptone solution furnished a more favorable medium for the bacteria, and thus enabled them to resist unfavorable conditions. Such an effect would, however, hardly be expected in so short a period as 40 minutes; and this explanation fails to account for the fact that the toxicity of the hydrochloric acid is much more diminished than that of the sulphuric acid. Reference to Tables 15–17, which show the results obtained with the organic acids, makes it still clearer that a specific chemical action is involved.

Evidently with the organic acids disinfectant power is much less affected by the presence of peptone. With *B. coli* acetic acid produces a 100 per cent reduction when in a strength of 0.0935

TABLE 15.

DISINFECTANT ACTION OF ACETIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
4,350	72.5	0.0725	1.60	1.16	50,000	00.00
4,750	79.3	0.0793	1.50	1.19	"	00.00
5,340	89.0	0.0890	1.40	1.25	"	25.00
5,975	97.0	0.0970	1.30	1.26	"	66.00
5,995	98.0	0.0980	1.30	1.27	"	61.72
6,861	114.2	0.1142	1.25	1.42	65,000	98.75
7,540	125.8	0.1258	1.15	1.45	"	93.30
8,360	139.5	0.1395	1.05	1.46	"	100.00
9,125	152.1	0.1521	1.03	1.57	"	100.00
16,475	174.5	0.1745	1.00	1.75	"	100.00
10,720	178.8	0.1788	1.00	1.78	"	.....
.....	210.0	0.2100	.....	....	"	.....
14,620	244.0	0.2440	0.90	2.20	"	100.00

TABLE 16.

DISINFECTANT ACTION OF BENZOIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
1,638	13.18	0.0132	6.4	0.84	70,000	28.6
1,720	14.11	0.0141	6.2	0.87	70,000	28.6
2,105	17.20	0.0172	5.8	1.00	100,000	0.0
3,365	27.60	0.0276	5.2	1.43	100,000	73.0
5,555	47.30	0.0473	3.2	1.51	100,000	100.0

TABLE 17.

DISINFECTANT ACTION OF BENZOIC ACID ON *B. typhi* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
1,434	11.72	0.0117	6.9	0.81	50,000	20.00
1,562	12.80	0.0128	6.6	0.84	50,000	20.00
2,155	17.80	0.0178	5.7	1.01	56,000	81.43
2,917	24.30	0.0243	4.9	1.19	56,000	100.00

normal. In the presence of peptone the required strength is 0.1395 normal. With *B. coli* the corresponding 100 per cent reduction strengths for benzoic acid are 0.0199 in water and 0.0473 in peptone solution. With *B. typhi* the respective strengths of benzoic acid are 0.0057 and 0.0243.

In a general way we may say that the presence of 1 per cent peptone solution diminishes the toxicity of hydrochloric acid, measured in terms of dissociated hydrogen, to from one-eighth to one-tenth its water value, and that of sulphuric acid to from one-fifth to one-eighth its water value. The toxicity of benzoic acid, measured in normality, is diminished under the same conditions to from one-fourth to one-half, and that of acetic acid to a little over one-half its water value.

The most probable explanation of this phenomenon is the formation of a loose compound between the proteid molecules and the acids which would diminish the toxicity of the latter, just as Stiles and Beers (1905) have shown that such a combination alters the effect of mineral salts on muscle.

Bugarzky and Liebermann (1898), Cohnheim and Krieger (1900), and other observers, have proved the existence of such loose compounds between proteids and acids by freezing-point determinations. We desired, however, to examine the actual substance used in our own experiments. Through the kindness of Dr. Raymond Haskell, of the Research Laboratory of Physical Chemistry of this Institute, determinations of electrical conductivity were made on the peptone solution used in our experiments, on a solution of hydrochloric acid in distilled water, and on a solution of the same strength in the peptone solution.

The specific conductivity of the peptone solution was 0.0004, showing that it was fairly pure. That of the hydrochloric acid solution 0.02 normal or 720 parts HCl per million, 90.46 per cent dissociated, was 0.007. The 1 per cent peptone solution containing 0.02 normal hydrochloric acid gave a conductivity of 0.002, showing that approximately four-fifths of the hydrochloric acid had been neutralized by the peptone.

It is evident that the effect of the peptone in decreasing the toxicity of the hydrochloric acid may be explained by the fact that the number of dissociated hydrogen ions is decreased by the peptone in the same degree. The effect would naturally be less marked, as we find to be the case, with sulphuric acid, since this acid is less ionized to start with. Finally, the un-ionized organic acids are least affected. The decreased toxicity which does occur with them may perhaps be due to a loose compound with their whole-molecule—what Stiles and Beers call a "physiological compound."

6. GENERAL CONCLUSIONS.

It appears from our experiments that the typhoid bacillus is highly sensitive to an excess of acid, being destroyed in an aqueous suspension by 40 minutes' exposure to a 0.005 normal solution of either hydrochloric, sulphuric or benzoic acid. The colon bacillus will endure exposure, under similar conditions, to solutions from two to four times as strong. Ninety-nine per cent of the bacteria in a suspension are killed by solutions of from one-half to two-thirds this strength, the last few organisms being especially resistant.

The mineral acids, hydrochloric and sulphuric, are fatal in concentrations at which they are highly dissociated. Their action runs parallel, not to their normal strength, but to the number of free hydrogen ions per unit volume. With the two organisms tested, both the 99 per cent and the 100 per cent reductions were affected, at the same concentration of dissociated hydrogen, whichever acid was used.

The organic acids, acetic and benzoic, are fatal to the typhoid and colon bacilli at a strength at which they are only slightly dissociated. The effect here appears to be due to the whole-molecule and is specific for each acid, acetic having only 10–20 per cent the toxicity of benzoic.

The presence of 1 per cent of peptone greatly diminishes the toxic action of acids, the action being somewhat less marked with sulphuric acid than with hydrochloric, and still weaker with the organic acids. In the case of hydrochloric acid we find that the diminished toxicity is accounted for by decreased ionization.

It is evident that the action of organic matter and other neutral substances in decreasing toxicity greatly complicates the study of disinfectant action. It will be necessary to bear this phenomenon in mind in considering the composition of culture media, since the apparent acidity, as determined by titration, may be quite different from the effective acidity which influences living organisms. With the mineral acids, any factor which affects dissociation, such as the presence of neutral salts of the same anion, will change the effective acidity. In considering the viability of disease germs in sewage and water, it is evident that differences in dilution and the effect of inorganic salts, organic matter, and suspended solids introduce such complex factors that detailed studies of specific local conditions are desirable.

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THE DETERMINATION OF SMALL QUANTITIES OF COPPER IN WATER.

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BY EARLE B. PHELPS.

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DURING the past few years the question of the addition of small quantities of copper salts to water supplies as a preventative of algal growths and as an emergency disinfectant against typhoid fever germs, has received much discussion and led to many important investigations in this country as well as abroad. One result of all this work has been to indicate the need of some simple yet accurate method for the determination of the small amounts of copper with which the investigator has to deal. The method recommended by the Committee on Standard Methods of Water Analysis of the Laboratory Section of the American Public Health Association,[1] is essentially that of Clark and Forbes.[2] It involves the concentration of a sufficient amount of the water to yield a weighable amount of copper, the precipitation of the copper as well as of certain other metals which may be present, as sulphides, and the separation from the mixed sulphides of the lead and iron by the usual methods. The copper is then deposited electrolytically and weighed. Quantities of copper as small as 2 or 3 mg. are thus determined by Clark and Forbes with a mean probable error of about 5 per cent., while the determination of 1 mg. obviously cannot be made with a probable error of less than 10 per cent. The disadvantages of the process are, first, the necessity for boiling down a large volume of water in order to get sufficient copper to weigh with accuracy, and, second, the length of time required and the liability of error introduced by the precipitations and separations involved.

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[1] "Report of the Committee on Standard Methods of Water Analysis," Jour. Inf. Dis. 1905, Sup. No. 1, p. 1.

[2] Mass. State Board of Health, 32d Ann. Rep. for 1900, p. 487.

Colorimetric methods, while generally much more sensitive than the gravimetric, are greatly influenced by the presence of other substances, especially other metals and organic coloring-matter.

The writer has had occasion to make a number of such copper determinations and was moreover limited by the experimental conditions to quantities of one liter for each determination. Since the water contained at times only a few tenths of a milligram of copper per liter, the standard method of procedure was obviously out of the question. As a result of a study of various possible methods for the determination, a procedure was devised which seemed to combine to a satisfactory degree the requisite sensitiveness, accuracy and simplicity. The method consists in the evaporation of a given volume of the water to about 100 cc. the electrolytic separation of the copper from the acidulated solution, the solution of the deposited copper in dilute acid, and its neutralization and colorimetric determination as sulphide, by comparison with standard tubes of known copper content. By this procedure it is easily possible to determine 0.1 mg. of copper, or if this amount were derived from a liter of water, 0.1 part per million. The accuracy is fully as great as with the gravimetric method using ten times as much of the same water.

The detailed procedure is as follows:

Apparatus.—Platinum dishes of about 100 cc. capacity to serve as anodes. Connection with the circuit is most conveniently made by placing the dish in a little mercury, contained in a shallow metal dish. To the latter is soldered a wire leading to the positive binding post.

A stout platinum wire, about 50 cm. long, 40 cm. of which is coiled into a flat spiral and whose end is fastened directly to the negative binding post. The spiral constitutes the cathode.

A convenient source of electrical current. The character of the current is not so important in this case as in gravimetric processes, since only small amounts of copper are dealt with and

SUMMARY OF COPPER DETERMINATIONS.

No.	Water.	Parts per million.		Characteristics of the water.	Substances added.	Mg. of copper.	
		Total solids.	Loss on ignition.			Taken.	Found.
1	Boston tap water....	40	15	Soft, colored, surface.	None.	0.54	0.52
2	Boston tap water....				None.	0.27	0.27
3	Boston tap water....				None.	0.27	0.24
4	Boston tap water....				None.	0.14	0.12
5	Boston tap water....				None.	0.14	0.12
6	Boston tap water....				Fe as $FeCl_3$, 5 mg.; Pb as acetate, 40 mg.	0.54	0.54
7	Boston tap water....				Ag as $AgNO_3$, 0.5 mg.; Sn as $SnCl_2$, 1.0 mg.	0.54	0.57
8	Chattahoochee, Ga..	300	50	Soft; solids are red iron clay.	None.	0.54	0.57
9	Pecos, N. Mex.......	2000	100	Hardness of 840 parts; turbid.	None.	0.54	0.54
10	Milk, Mont...........	750	.....	Hardness of 620 parts; clear.	None.	0.54	0.55
11	Colorado, Tex........	300	.....	Hardness of 128 parts; turbidity of 110.	None.	0.54	0.52
12	Boston sewage..	4000	810	Chlorine abnormal, about 1500.	None.	0.54	0.50
13	Hay infusion.........	.....	.....	Color about 300.	None.	0.54	0.55
14	Straw board waste..	7000	4000	High in CaO and organic acids.	None.	0.54	0.51

the deposit need not be washed or dried. In the present experiments the current was supplied by two "gravity cells" in series, yielding a current through the solution of about 0.02 ampere. The current density at the cathode was about N. $D_{100}=0.3$ ampere.

Nessler jars of the short type holding 100 cc.

Reagents.—Standard copper solution. About 0.8 gram of clean copper sulphate crystals are dissolved in water and, after the addition of 1 cc. concentrated sulphuric acid, the volume is made up to one liter. In 100 cc. of this solution the copper is determined in the usual way by electrolytic deposition and weighing and the solution is diluted so that 1 cc. contains 0.2 milligram copper. This solution is permanent.

Potassium sulphide reagent. An alkaline solution of potassium sulphide made by mixing equal volumes of 10 per cent. potassium hydroxide solution, and a saturated solution of hydrogen sulphide in water.

Nitric acid one to three and sulphuric acid one to one, both tested for copper.

The Determination.—Of waters carrying from 0.1 to 1.0 part copper one litre is taken. For other concentrations take proportionate amounts. Evaporate to about 75 cc. and wash into the platinum dish. Add 2 cc. of the dilute H_2SO_4 for clear and soft waters. For alkaline waters an additional amount is used to offset the alkalinity. For waters carrying much organic matter or clay, 5 cc. of acid are added to assure the formation of a soluble copper salt. The dish is then placed in position, the cathode suspended in the solution so that it is parallel to and about half an inch from the bottom, and the circuit is closed. Electrolyze for about four hours with occasional stirring, or over night, if convenient. Lift out the cathode without previously having opened the circuit, and immerse the spiral in a small amount of the dilute nitric acid, previously heated to boiling. Wash off the wire and evaporate the nitric acid solution to dryness on the water-bath. If silver is suspected to be present, add a few drops of hydrochloric acid before evaporation. Take up in water and wash into the Nessler jar. Make up to the mark and add 10 cc. of the sulphide reagent. The color of the copper sulphide develops at once and is fairly permanent, lasting for several hours, at least. A similar tube is prepared by adding 10 cc. of the reagent to a tube of distilled water and then adding standard copper solution in 0.2 cc. portions until the colors of the two tubes match. If one litre of water were originally taken, each cubic centimeter of standard solution used represents 0.2 part per million of copper.

The method has been carefully tested as to the completeness of the separation and as to the influence of other substances in the water. Particular care has been taken to separate small amounts of copper from large amounts of organic matter (sewage and industrial wastes), coloring-matter in surface waters, and from salts of iron, lead, silver and tin. As will be seen from the appended table of results the separation is in all cases satisfactory. Silver and tin appear to be, according to the authorities, the only metals which will separate out under the conditions used. Neither will be commonly met with. The silver may be converted into the chloride as indicated and does not interfere with the determination. The tin is only partially dissolved by the nitric acid and during the evaporation is converted into metastannic acid. In the alkaline solution used in the test the tin in this form does not interfere in the least.

In the accompanying table are given the results obtained in testing this method. In all cases except those in which Boston sewage and straw-board liquor (the waste liquor of a straw-board mill) were used, one litre of water was taken and the necessary solutions added to it. In the two cases mentioned only 100 cc. were taken.

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THE INHIBITING EFFECT OF CERTAIN ORGANIC SUBSTANCES UPON THE GERMICIDAL ACTION OF COPPER SULPHATE.*

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INTRODUCTION.

THE germicidal action of copper salts dissolved in water has frequently been found to depend largely upon the character of the water itself. Ellms (1905) has pointed out the influence of the hardness and turbidity of the water. Johnson and Copeland (1905) found that in a sewage effluent, to which a large number of typhoid organisms had been added, an amount of copper sulphate equal to a concentration of 20 parts of copper per million reduced the number of bacteria from 1,300,000 to 600 per cubic centimeter in 15 hours. In distilled water, other conditions being the same, the reduction was from 1,300,000 to 11. Kraemer (1905) and Basset-Smith (1905) have both shown that the toxic action of copper on the typhoid organism is much greater in distilled water than in tap water.

It is not difficult to determine the nature of the influence exerted by mineral impurities in the water. Dissolved carbonates bring about a direct precipitation of the copper. Even such insoluble material as kaolin has been shown by Sullivan (1905) to possess the power of reacting with copper salts, in some cases completely removing the copper from solution. True and Oglevee (1905) have confirmed the earlier results of Nägeli showing that adsorption often plays an important rôle, and that powdered glass or sand may destroy in large measure the toxic action of dilute metallic solutions.

In case of organic impurities the nature of the influence is not quite so clear. Direct precipitation of the copper may occur, especially in sewages. On the other hand, the presence of certain classes of organic matter, such as leaf infusion, has been shown to prevent the precipitation of copper by alkaline carbonates (Ellms, 1905). In such

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cases it must be assumed that certain organic compounds are formed. If such compounds are found upon investigation to be non-toxic, or to have a lower toxic value than the original copper salt, this fact may throw some light upon the nature of the toxic action itself.

It was the purpose of the present investigation to study the germicidal action of copper sulphate upon the typhoid organism in distilled water and in the presence of certain organic compounds. Organic substances were selected which would not in any case precipitate the copper, and which, according to the chemical evidence, do not form any direct union with it. This does not preclude the formation of a "physiological compound," as defined by Stiles and Beers (1905), namely, a compound which is not readily detectible by chemical means, but which possesses characteristic physiological properties. For this purpose dextrose and peptone were used. The organic matter occurring naturally in Boston tap water, a colored surface water, was also studied.

METHODS.

Preparation of copper sulphate.—The copper sulphate used was carefully prepared to assure a pure product. In particular was it desired to obtain salt free from ammonia, since there is reason to believe that the double or cuprammonium salt will have a distinctly different toxic effect from that of the simple copper salt. Some "C. P." copper sulphate crystals were dissolved in water, making about a 10 per cent solution. To this solution a small amount of Na_2CO_3 was added, and the solution was boiled for some time to expel the ammonia. It was then acidified and submitted to electrolysis with a small current, about 0.05 ampere, and a potential difference through the solution of about one volt. Copper was deposited on the inside of a platinum dish which served as a cathode. This deposit of copper was then washed with ammonia-free water and redissolved in dilute sulphuric acid by reversing the current. The product obtained by crystallizing this solution was recrystallized from ammonia-free water to free it from the last traces of acid. It was dried for several days over calcium chloride and caustic potash.

Preparation of potassium sulphate.—This salt was prepared by twice recrystallizing the best Merck preparation from ammonia-free water.

Tenth-molar (fifth-normal) solutions of these salts were made up. For use 1 c.c. of these solutions was diluted to 100 with ammonia-free water. In the following tabulated results all references to the salt solutions are to these dilute (N/500) solutions.

The organic compounds.—Witte's peptone and Merck's "C. P." dextrose were used.

The typhoid cultures.—The culture used (No. 2006) was one of those used in some earlier work. It was obtained from Dr. J. H. Wright, of the Massachusetts General Hospital. It was taken from the spleen at an autopsy on May 26, 1905. The clinical diagnosis was typhoid fever. The culture, according to Wright, gave all the ordinary tests for typhoid fever, including the Widal test.

It was submitted to the ordinary diagnostic tests, with the following results: fermentation tube with dextrose broth, growth in closed arm, acid produced, no gas; milk not coagulated, slight acid production; no indol from peptone; nitrates reduced slightly; gelatin not liquefied in two weeks; growth on agar slant, scanty, thin, translucent; it reacts with the sera of two rabbits into which two other strains of typhoid organisms had been introduced subcutaneously.

Cultures A, B, and C were obtained from plates made from Bottle 2 in Experiment 5. They had lived for 48 hours in the presence of a concentration of 0.63 parts of copper per million in distilled water. They gave all the above tests exactly as the original culture, except that they were not submitted to the Widal test.

Technique of the experiments.—The experiments were made under as uniform conditions as possible, and in the following manner:

In all cases, except where tap water is specified, sterilized ammonia-free water was used. When dextrose or other solutions were used, these were made up with ammonia-free water and sterilized. The organism was grown for 24 hours at 37° on the surface of an agar slant. A loop of the culture was then removed and placed in 100 c.c. of water. After thorough shaking, proper amounts of this suspension were added to the bottles of water in which the experiments were to to be made. These bottles were then thoroughly shaken, and the the bacteria determined in each by properly diluting 1 c.c. and plating. For plating agar was used, and all plates were grown for 15 hours at 37° C. The salt solution was then added. In the same manner determinations of the numbers of organisms present were made at intervals during the experiment, as indicated in the tabulated results.

In the following tables the full details of each experiment are first given, including the actual bacterial counts. In order to compare the various experiments, the bacterial results have been calculated

EXPERIMENT 1.

STARTED JANUARY 24, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	COUNTS Initial	5 Min.	64 Hrs.	24 Hrs.
1	98	0.6	...	12	0.38	380,000	125,000	6,000	42
2	98	1.0	...	20	0.63	400,000	45,000	1,700	12
3	100	2.0	...	40	1.26	350,000	25,000	300	9
4	98	...	0.6	12	....	370,000	......	370,000	50,000
5	98	...	1.0	20	....	410,000	......	460,000	45,000
6	99	...	2.0	40	....	400,000	......	400,000	43,000

Temperature, 20°–22°.

EXPERIMENT 2.

TAP WATER—STARTED JANUARY 29, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ So. (c.c.)	K_2SO_4 So. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	COUNTS Initial	1 Min.	10 Min.	30 Min.	6 Hrs.	29 Hrs.
1	89	0.4	...	8.8	0.28	170,000	180,000	170,000	170,000	110,000	9,800
2	94	0.8	...	16.8	0.53	180,000	......	......	......	50	510
3	84	1.2	...	28.0	0.88	190,000	......	......	......	......	100
4	90	2.0	...	44.0	1.39	150,000	......	......	......	......	80
5	88	3.0	...	66.0	2.08	180,000	120,000	100	100	50	0
6	88	...	0.4	8.8	....	140,000	......	......	......	......	240,000
7	89	...	0.8	18.0	....	160,000	......	......	......	......	336,000
8	90	...	1.2	26.0	....	180,000	......	......	......	......	92,000
9	95	...	2.0	42.0	....	170,000	......	......	......	......	69,000
10	92	...	3.0	66.0	....	200,000	......	......	......	......	80,000

Temperature, 20°–23°.

EXPERIMENT 3.

STARTED FEBRUARY 6, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	COUNTS Initial	1 Hr.	6 Hrs.	24 Hrs.
1	100	0.5	...	10	0.31	125,000	.....	5,300	8
2	99	1.0	...	20	0.62	135,000	.....	700	6
3	105	2.0	...	40	1.24	140,000	.....	400	9
4	98	3.0	...	60	1.86	128,000	80,000	130	0
5	99	...	0.5	10	....	140,000	.....	120,000	80,000
6	97	...	1.0	20	....	136,000	.....	100,000	70,000
7	98	...	2.0	40	....	132,000	.....	100,000	63,000
8	98	...	3.0	60	....	140,000	.....	120,000	56,000

Temperature, 20°–22°.

into percentage of the initial numbers, and these results have been used in the discussion of the table.

In each case in which copper sulphate was used the control contained an equimolar amount of potassium sulphate. The controls therefore differed from the tests simply in the substitution of potassium for the copper.

EXPERIMENT 4.

STARTED FEBRUARY 13, 1906.

Bottle No.	Water		Dextrose (gm.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	Counts				
	Kind	c.c.						Initial	3 Hrs.	6 Hrs.	23 Hrs.	48 Hrs.
1	Best	98	..	0.5	...	10	0.31	540,000	1,800	1,400	660	660
2	"	99	..	1.0	...	20	0.63	540,000	400	100	46	350
3	"	99	1	0.5	...	10	0.31	560,000	415,000	640,000	190,000	4,300
4	"	98	1	1.0	...	20	0.63	500,000	170,000	82,000	100	600
5	Tap	90	..	0.5	...	10	0.31	540,000	134,000	2,000	125	9
6	"	87	..	1.0	...	20	0.63	560,000	6,300	700	15	2
7	Best	98	..	...	1.0	20	....	500,000	......	520,000	95,000	10,000
8	"	98	1	...	1.0	20	....	500,000	......	490,000	200,000	420,000
9	Tap	90	..	...	1.0	20	....	540,000	......	600,000	110,000	1,200

Temperature, 20°–24°.
"Best water" is ammonia-free, distilled water.

EXPERIMENT 5.

STARTED FEBRUARY 15, 1906.

Bottle No.	Water (c.c.)	Dextrose (gm.)	$CuSo_4$ Sol. (c.c.)	K_2So_4 Sol. (c.c.)	Concent. of Salt, (N/1,000,000)	Copper (Parts per Mill.)	Counts			
							Initial	6 Hrs.	24 Hrs.	48 Hrs.
1	100	..	0.5	...	10	0.31	30,000	600	184	40
2	100	..	1.0	...	20	0.63	26,000	200	70	23
3	99	1	0.5	...	10	0.31	26,000	1,300	1,800	900
4	100	1	1.0	...	20	0.63	38,000	contam	inated	
5	98	..	...	0.5	10	....	28,000	30,000	14,000	9,000
6	99	..	...	1.0	20	....	30,000	27,000	10,000	.....
7	99	1	...	0.5	10	....	24,000	25,000	12,000	.....
8	98	1	...	1.0	20	....	24,000	21,000	13,000	8,000

Temperature, 22°–24°.

EXPERIMENT 6.

STARTED FEBRUARY 20, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Culture	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	Counts	
							Initial	24 Hrs.
1	98	1	..	2,006	20	0.63	44,000	460
2	98	..	1	"	20	....	50,009	49,000
3	99	1	..	A	20	0.63	69,000	600
4	98	..	1	"	20	....	90,000	44,000
5	98	1	..	B	20	0.63	45,000	400
6	97	..	1	"	20	....	48,000	26,000
7	98	1	..	C	20	0.63	61,000	600
8	98	..	1	"	20	....	67,000	25,000

Temperature, 21–23°.

EXPERIMENT 7.

STARTED MARCH 5, 1906.

Bottle No.	Water (c.c.)	Pepton (gm.)	Culture No.	$CuSO_4$ Sol. (c.c.)	Concentration of Salt (N/1,000,000)	Copper (Parts per Mill.)	COUNTS	
							Initial	24 Hrs.
1	100	0	2,006	0.5	10	0.31	179,000	1,040
2	100	0	"	2.0	40	1.24	189,000	3
3	101	0	A	0.5	10	0.31	2,400	3
4	100	0	"	2.0	40	1.24	2,200	0
5	98	1	2,006	0.5	10	0.31	171,000	2,420,000
6	101	1	"	2.0	40	1.24	175,000	455,000
7	99	1	A	0.5	10	0.31	2,800	19,500
8	98	1	"	2.0	40	1.24	2,900	15,000

Temperature, 20°–24°.

DISCUSSION OF RESULTS.

Effect of organic matter in tap water.—In comparing the results of these experiments, the basis of comparison will be the number of surviving organisms in each case, expressed as percentage of the initial number. Other bases of comparison suggest themselves, but the one selected appears on the whole to be the most logical. In this way the effect of the copper upon those few comparatively resistant organisms, always found in experiments of this nature, is given predominant importance, while the effect upon that large percentage of organisms which is killed in all the experiments has comparatively little weight.

Such a comparison of the average results of Experiments 1 and 3, best water, with those of Experiment 2, tap water, gives the following figures:

Concentration of Copper (N/1,000,000)	PER CENT SURVIVING—24 HRS.		Ratio $(b+a)$
	Best Water (a)	Tap Water (b)	
10	0.009	5.800	644
20	0.004	0.280	70
40	0.004	0.053	13
60	0.000	0.000	

It is quite evident that the organic matter present in the tap water inhibits the toxic action of the copper, but the significant fact here is that there is no definite point in the series at which the addition of more copper to the tap water will produce a normal killing effect such as is produced in pure water. The effect of the organic matter cannot be neutralized up to the concentration required for the complete elimination of the organisms. It would appear, therefore, that the apparent inhibition of the toxic effect of the copper is due to the formation of some non-toxic compound; that the formation of this compound is due to a reversible reaction which is complete only at the highest concentration of copper used; and that below this point the addition of increasing amounts of copper simply brings about a further reaction toward this non-toxic compound, producing a new condition of equilibrium according to the law of mass action.

Dextrose.—The effect of dextrose upon the copper sulphate seems to be of a quite different nature. The following figures are calcu lated from the results of Experiment 4:

Concentration of Copper (N/1,000,000)	PER CENT SURVIVING—24 HRS.		Ratio ($a \div b$)
	Without Dextrose (a)	With Dextrose (b)	
10	0.12	34.0	283.0
20	0.009	0.02	2.2

In the lower concentration dextrose neutralizes completely the toxicity of the copper, so that the effect is about equal to that in the control (Bottle 8). In the higher concentration the effect of the dextrose is almost nil. This result, taken in connection with the fact that the concentration of the dextrose is about $\frac{1}{18}$ molar, and that there are accordingly over 10,000 $C_6H_{12}O_6$ molecules to each copper ion in the one case and over 5,000 in the other, leads to the conclusion that the results obtained are not due to the formation of a non-toxic compound. A careful study of the electric conductivity of these solutions did not reveal any decrease in the normal conductivity of the copper due to the presence of dextrose. It may be presumed, however, that what has been called a "physiological compound" might be readily broken down under the influence of the electric current.

The following assumption seems to be in agreement with all the facts: The bacteria doubtless attract to themselves by a process of adsorption a certain amount of dextrose, and are thus surrounded by a solution of this sugar more concentrated than that existing in the water. This tends to produce a difference in osmotic pressure between the free solution and this surrounding layer, and it may be that a certain definite concentration of the copper ions is necessary before this film of "osmotic tension" can be pierced. An analogous case is that of surface tension, which presents a certain resistance to the entrance of a non-wetted body.

Peptone.—Peptone was the third substance studied. The results of Experiment 7 show that a 1 per cent solution of peptone allows the typhoid organism to multiply even in the presence of rather strong copper-sulphate solution. Owing to the high electric conductivity of the rather impure peptone, the results of conductivity determinations are uncertain. There seems to be little doubt here, however, that an actual combination has taken place between the copper and the peptone. The addition of sufficient copper solution to the peptone solution to give a distinct color resulted in the formation of a colloidal-like solution, of a robin's-egg blue color.

These results have an important bearing upon many practical points in connection with the use of copper sulphate for the destruction of the typhoid organism. Results obtained in the laboratory in distilled water are not in the least indicative of what may be expected under field conditions. Neither are actual field results on one water reliable criteria for the undertaking of similar work upon another. The impracticability of the internal use of copper sulphate in the treatment of typhoid fever is also suggested by the results obtained with peptone.

Selection of a resistant strain.—Cultures A, B, and C were taken from Bottle 2 in Experiment 5, and had lived for 48 hours in a solution of copper sulphate containing 0.63 parts of copper per million. They were used in Experiments 5 and 6 in parallel with the original strain in order to determine whether they possessed any increased resistance to copper. The results are all negative, indicating that these strains are not more resistant than is the parent strain.

The time factor in the germicidal effect.—In Experiments 1, 3, and 4, where determinations of the numbers of organisms were made at various intervals during the experiment, it is seen that even in the more dilute solution used there is a very rapid falling-off in numbers during the earlier part of the test. In Experiment 1, for instance, the reduction in 5 minutes was 67 per cent in a concentration of 0.38 parts of copper per million, but all the organisms had not been killed in 24 hours. Such results indicate an extreme range of resistance to copper among these organisms. The 42 organisms which survived the treatment for 24 hours lived 288 times as long as the 250,000 which died in less than 5 minutes.

Effect of concentration.—This great variability is also shown in a study of the effect of various concentrations.

The average percentage survival after 24 hours in all experiments with 0.38 parts of copper per million was 0.19; with 0.76 parts, 0.07; with 1.26 parts, 0.04. Notwithstanding the fact that 99.8 per cent are killed by a concentration of 0.38 parts,. there are still 0.04 per cent which can withstand the action of a copper solution four times as concentrated.

This tremendous variability is of vital importance, not only in questions of sterilization of water by heat, freezing, or chemicals, in all of which cases such a variability has been shown to exist, but in the far more important questions of the self-purification of streams and the longevity of the typhoid bacillus in the water. Most cases of typhoid fever, contracted from drinking-water, have undoubtedly come from these few resistant forms rather than from those which are known to have perished in the natural stream. A removal of 99.99 per cent of the typhoid organisms may sound like security but actually means high typhoid rates. The importance of this residual hundredth of a per cent cannot be overestimated, owing to the very fact that it is so resistant.

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EXPERIMENTS ON THE STORAGE OF TYPHOID INFECTED WATER IN COPPER CANTEENS.

BY EARLE B. PHELPS, BOSTON, MASS.

(United States Geological Survey. Published by Authority of the Director, U. S. Geological Survey.)

EXPERIMENTS ON THE STORAGE OF TYPHOID INFECTED WATER IN COPPER CANTEENS.*

By EARLE B. PHELPS, Boston, Mass.

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One of the most striking results of the researches of Moore and Kellerman on the germicidal effect of copper salts on microscopic organisms is the discovery that water brought into contact with metallic copper will dissolve enough of the metal to become distinctly toxic to typhoid and cholera germs. Kraemer and others, following up this line of research, have found that clean copper tanks, or copper strips suspended in water, exert a germicidal action. The use of copper canteens in the army and in other services where water is transported in small quantities naturally suggested itself. The hydrographic branch of the United States Geological Survey before distributing such canteens among its field parties instructed the writer to make an investigation of the whole subject to determine the value of the project. The work has been carried out during the past summer at the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology under the charge of Mr. Marshall O. Leighton, Hydrographer-in-charge of the division of Hydro-economics of the Geological Survey.

The canteens used were of the regular army pattern made entirely of sheet copper, and when full held two quarts of water. The superficial area of copper exposed to the water when the canteen is full is 830 square centimeters or 44 square centimeters per 100 cc. of water. When holding one liter of water, the amount employed in the present experiments, the surface exposed is about 40 square centimeters per 100 cc. These figures are of interest in comparing the present experiments with those of Moore and Kellerman and of Kraemer. Moore exposed surfaces of 40 and 160 square centimeters respectively per 100 cc. of water, while Kraemer used surfaces of about 45 square centimeters per 100 cc.

CULTURES USED.

Three cultures of *B. typhosus* were used as follows:

Culture No. 2001. This culture was obtained from the laboratory of the Boston City Board of Health. It was originally obtained from the

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***(From the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology.)**

Massachusetts General Hospital in 1902. It agrees with the ordinary tests for *B. typhosus,* gives the Widal reaction with known typhoid blood, reacts with rabbit serum artificially prepared by inoculation of another culture (No. 2005), and produces in a rabbit a reaction against that other organism.

Culture No. 2005. This culture was obtained in the fall of 1904 from the Boston City Hospital and is in daily use at the laboratory of the Boston Board of Health in Widal tests. It reacts with known typhoid blood, and with rabbit serum prepared by inoculation with culture No. 2001, and produces in a rabbit a reaction against that organism.

Culture No. 2006. This culture was obtained from Dr. J. H. Wright, of the Massachusetts General Hospital. It was taken from the spleen at an autopsy on May 26, 1905. The clinical diagnosis was typhoid fever. The culture according to Wright gives all the tests for *B. tphosus* including the Widal reaction. It reacts in the writer's hand with the artificially prepared sera described above.

METHODS EMPLOYED.

The canteens were cleaned originally by treatment with alkaline potassium permanganate which was allowed to stand in them over night. They were then rinsed in dilute oxalic acid solution and rinsed thoroughly with water. Since the beginning of the experiments they have not been cleaned. In all the experiments here described the mode of procedure was as follows:

An agar culture of the organism to be used was grown for fifteen hours at 37° C. From this culture a suitable dilution in tap water was made. About ten cubic centimeters of this strong water suspension were then added to a liter of non-sterile water, well mixed by shaking, and poured into the canteen. A second liter prepared in exactly the same way was poured into a second canteen and a third similar liter was poured into a glass bottle as a control. The controls were in all cases kept dark by wrapping in dark paper. Duplicate plates were immediately made from all three tests with suitable dilutions. In this way the water was inoculated with from 50,000 to 150,000 organisms per cubic centimeter. The water also was plated out and frequent blank plates were made as a check on the technique. The temperature of the air and of the water was noted. In each series two of the three cultures were used.

The number of organisms remaining in the water at the end of twenty-four hours and, in some cases, at the end of shorter periods was determined by plating on agar. All media used in this work were made according to the methods recommended by the American Public

Health Association. The plates were incubated at 37° for fifteen hours. In counting, the colonies were carefully examined and all colonies which were not typical typhoid colonies were rejected in the count. A number of these colonies which appeared to be typical typhoid colonies were fished from each plate and submitted to the Widal test. For this test I have prepared two rabbits by inoculation with cultures No. 2001 and No. 2005, so that their blood would cause the typical agglutination of the organism. All the colonies fished and tested in this way gave the reaction, thus eliminating all reasonable doubt as to the identity of the organisms in question.

At the conclusion of each experiment the copper dissolved by the water was determined. For this purpose a liter of the water was evaporated to small bulk made acid with sulphuric acid and placed in a platinum dish. The copper was then electrolytically deposited from the solution upon a spiral of platinum wire. In this way the copper was quite completely separated from other dissolved and suspended material of the water with the exception of certain metals which may be deposited with it under such conditions. The deposit was dissolved from the platinum wire in nitric acid, neutralized with ammonia, diluted, and treated with a solution of potassium ferro-cyanide. The resulting color was compared with copper standards prepared in the same way and containing known amounts of copper. A few tests of this method upon known amounts of copper dissolved in tap water indicate that its accuracy for amounts comparable with those found in these studies is within five per cent.

Three series of experiments were carried out. In the first Boston tap water was used, the object being to determine what progressive decrease, if any, would take place in the efficiency of the canteen due to the corrosion or coating over of the surface exposed to the water. Eight successive experiments were made. The effect of shorter time intervals than twenty-four hours was also studied in experiments two and three of this series. The second series consisted of a study of several waters from other localities. These waters were from the Chattahochee at Atlanta, Georgia, the Pecos at Carlsbad, New Mexico, the Colorado at Austin, Texas, and the Milk at Chinook, Montana. One experiment was made on each of the first three waters and two on the Milk River water. The third series of experiments was made on Boston tap water with the canteens which had been used in Series II and which had not been cleaned in the meantime. This set consisted of four experiments, one with each canteen which had been used with the four waters mentioned above. The effect of copper upon the typhoid organisms in Boston water having been quite clearly shown in Series I, no organisms were added in this series. The determinations of copper were made at the end of twenty-four hours.

The results of the first series of experiments are shown in the following tables:

SERIES I. Boston Tap Water.

EXPERIMENT 1. JUNE 8–9.

Canteen.	Culture.	Numbers of *B. typhosus* per cubic centimeter.	
		Initial.	24 hours.
1	2001	100,000	6
		120,000	4
2	2001	130,000	4
		90,000	7
3	2005	140,000	12
		90,000	10
4	2005	100,000	12
		100,000	15
Control			
1	2001	120,000	80,000
		100,000	70,000
2	2005	110,000	40,000
		110,000	60,000

Bacteria in water at start, 25.
Blank 0.
Temperature, Water, 17° C. — 23° C. Air, 22° C. — 28° C.
Copper in water at conclusion, 1.95 parts per million.

EXPERIMENT 2. JUNE 12–14.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.				
		Initial.	Six Hours.	Fifteen Hours.	Twenty-one Hours.	Twenty-four Hours.
1	2001	100,000	75,000	13,000	110	15
		91,000	73,000	14,000	120	12
2	2005	100,000	70,000	10,000	100	8
		100,000	65,000	12,000	70	6
Control						
1	2001	120,000				80,000
2	2005	100,000				90,000

Temperature, Water at start, 18° C. Air, 20°-30°.
Copper in water at conclusion, 1.51 parts per million.

EXPERIMENT 3. JUNE 20–21.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.			
		Initial.	Six Hours.	Eighteen Hours	Twenty-four Hours.
1	2005	110,000	100,000	750	14
2	2005	90,000	80,000	800	17
3	2006	73,000	40,000	340	8
4	2006	70,000	30,000	400	9
Control					
1	2005	100,000			80,000
2	2006	80,000			70,000

Bacteria in city water at start, 14.

Temperature, Water at start, 18° C. Air, 20°-30°.

Copper in water at conclusion, 1.30 parts per million.

EXPERIMENT 4. JUNE 25–26.

Canteen.	Culture.	Number of B. *typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	120,000	0
2	2001	90,000	0
3	2006	160,000	3
4	2006	110,000	2
Control			
1	2001	110,000	70,000
2	2006	130,000	80,000

Bacteria in city water at start, 23.

Temperature, Water at start, 18° C. Air, 28°-32°.

Copper in water at conclusion, 1.2 parts per million.

EXPERIMENT 5. JUNE 30-JULY 1.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	70,000	7
2	2001	70,000	9
3	2006	95,000	4
4	2006	100,000	3
Control			
1	2001	80,000	80,000
2	2006	100,000	90,000

Bacteria in city water at start, 17.
Temperature, Water at start, 20° C. Air, 25°-30°.
Copper in water at conclusion, 1.2 parts per million.

EXPERIMENT 6. SEPT. 1-2.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	83,000	25
2	2001	95,000	32
3	2006	68,000	43
4	2006	73,000	30
Control			
1	2001	90,000	55,000
2	2006	78,000	40,000

Bacteria in city water at start, 14.
Blank, 0.
Temperature, Water at start, 18° C. Air, 28° C.
Copper in water at conclusion, 0.7 parts per million.

EXPERIMENT 7. SEPT. 4-5.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2005	110,000	28
2	2005	115,000	24
3	2006	78,000	40
4	2006	80,000	33
Control			
1	2005	100,000	55,000
2	2006	78,000	48,000

Bacteria in city water at start, 24.
Blank, 0.
Temperature, Water at start, 19° C. Air, 20°-25°.
Copper in water at conclusion, 0.5 parts per million.

EXPERIMENT 8. SEPT. 9-10.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	75,000	24
2	2001	75,000	21
3	2006	95,000	33
4	2006	105,000	36
Control			
1	2001	95,000	43,000
2	2006	90,000	50,000

Bacteria in city water at start, 27.
Blank, 0.
Temperature, Water at start, 20° C. Air, 29° C.
Copper in water at conclusion, 0.5 parts per million.

The results of the first series bring out several points of interest. It will be noticed that in only one case were the organisms reduced to less than one per cubic centimeter. One is, of course, tempted to consider here that the percentage reduction was very great and to reason that if there had been initially only a few organisms present then the elimination would have been complete. Unfortunately we know little of the cause for the great range of variation in the resistance of individual organisms to an unfavorable environment, but it seems probable that such resistances to different kinds of unfavorable environment are more or less correlated so that the organism which is resistant to copper may be the very one which has survived the unfavorable environment of the stream or well. Kraemer found a greater resistance on the part of a typhoid culture grown on agar for 24 hours than with the same culture grown for 15 hours, an observation which has an interesting bearing on this question.

The fact that organisms do survive the copper treatment even in small numbers, seems, in the writer's view, to lessen considerably the value of the canteen as a safeguard against typhoid infection.

A second point of interest is the fact that the efficiency of the canteen decreases as time goes on, probably owing to the accumulation on the surface of the copper of a film of basic carbonate or other insoluble copper compound. The fact that in only eight successive treatments with water the efficiency was seriously reduced indicates that for actual service frequent cleanings of the canteen with acid would be necessary. For this purpose oxalic acid would serve admirably and the cleaning of the canteen might not prove entirely impractical even under field or camp conditions. Between experiments 5 and 6 there was a period of two months during which the canteen stood dry. It will be noticed that a much greater difference is found between the results of these two experiments than between those of any other successive experiments. Plainly the deterioration of the surface goes on in the air as well as under water.

The two experiments in which the time element was varied show that twenty-four hours is the shortest time which should be allowed for anything like a complete removal of the organisms. Although other investigators under laboratory conditions with sterilized water and clean copper plates have found periods of even two hours sufficient to remove completely all typhoid organisms from the water, yet we find that under conditions as nearly as possible like those of actual service a much greater time is necessary and the removal of the organisms is not nearly so satisfactory.

The fact that the three strains of *B. typhosus* used in these experiments gave practically the same results throughout deserves mention. It has already been stated that these cultures have been on artificial media for periods of three years, eight months, and six weeks, respectively. Jackson has found a very marked resistance to copper on the part of freshly isolated cultures, and it might have been expected that a difference would have manifested itself in this case. On the contrary the three cultures acted very much alike, the advantage being first with one and then with another.

The chemical characteristics of the water probably more than any other factor will determine the result of such experiments as these, and differences in the water used doubtless explain very largely the differences in the results obtained by various observers. Especially would it appear that the results obtained by the use of distilled water are not at all comparable with those from natural waters. Moreover, the mere act of sterilizing water by heat may profoundly alter the chemical nature of its impurities and lead to correspondingly abnormal results. The differences noted by Kraemer between waters treated in various ways well illustrated this point, and more recent work by Bassett-Smith illustrated even more forcibly the different results obtained by distilled water and tap water. This matter seemed so important that the second series of experiments was planned in order to learn what effect water of various types would have upon the germicidal action of the copper canteen. The four waters used were collected from various parts of the country, and each is typical of certain peculiar conditions. The turbidity and various forms of hardness and the alkalinity were determined on each water, together with the iron, chloride and sulphate. The results are shown in the following table:

Water.	Turbidity.	Alkalinity. Carbonates and Bicarbonates as $CaCO_3$.	Total Hardness. Calcium and Magnesium as $CaCO_3$.	Carbonates of Sodium and Potassium as Na_2CO_3.	Carbonates of Calcium and Magnesium as $CaCO_3$.	Bicarbonates of Calcium and Magnesium as $CaCO_3$.	Free CO_2.	Iron.	Chorides as Cl.	Sulphates as SO_3.
Milk	0	500	620	0	62	438	0	0	120	380
Pecos	150	150	840	0	0	150	0	0.6	940	1,080
Chattahoochee .	400	9.5	17.5	....	0	0	+	5.2	68	35
Colorado	110	137	127	11	5	122	0	0.4	3	0

The water of the Milk River was free from turbidity, but carried a large amount of alkaline earth bi-carbonates, and little calcium or magnesium in any other form. That of the Pecos had a much smaller carbonate or bi-carbonate content, also due wholly to the alkaline earths, but was very high in the so-called incrustants — other salts of calcium and magnesium; its turbidity also was low. The Chattahoochee was very turbid water with no incrustants and a very low alkalinity. The Colorado carried some turbidity together with a moderate hardness due entirely to bi-carbonates — that is, without incrustants; there were present also in this water about ten parts per million of alkaline carbonates.

The results of the five experiments made with these waters are shown in the following tables:

SERIES II. HARD AND TURBID WATERS.

EXPERIMENT 1. JULY 26.

Milk River Water. Culture 2001.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	95,000	80,000
2	100,000	83,000
Control 1	100,000	70,000

Bacteria in water at start, 54.
Same after twenty-four hours in canteen, 40.
Temperature, Water at start, 28° C. Air, 30°.
Copper in water at conclusion, 0.2 parts per million.

EXPERIMENT 2. JULY 26.

Chattahoochee River Water. Culture 2001.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	120,000	50
2	120,000	40
Control		
1	110,000	80,000

Bacteria in water at start, 550.
Same after twenty-four hours in canteen, 500.
Temperature, Water at start, 28° C. Air, 30°.
Copper in water at conclusion, 1.5 parts.

EXPERIMENT 3. AUG. 18–19.

Milk River Water. Culture 2006.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	100,000	780
2	100,000	920
Control		
1	110,000	70,000

Bacteria in water at start, 50.
Same after twenty-four hours in canteen, 54.
Temperature, Water at start, 26° C. Air, 26°.
Copper in water at conclusion, 0.3 parts per million.

EXPERIMENT 4. AUG. 18–19.

Pecos River Water. Culture 2006.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	110,000	100
2	100,000	140
Control 1	100,000	100,000

Bacteria in water at start, 70.
Same after twenty-four hours in canteen, 50.
Temperature, Water at start. 26° C. Air, 26°.
Copper in water at conclusion, 0.5 parts per million.

EXPERIMENT 5. AUG. 18–19.

Colorado River Water. Culture 2006.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-one Hours.
1	105,000	8
2	100,000	2
Control 1	130,000	60,000

Bacteria in water at start, 75.
Same after twenty-four hours in canteen, 51.
Temperature, Water at start, 26° C. Air, 26°.
Copper in water at conclusion, 1.6 per million.

TABLE OF AVERAGE RESULTS.

Water.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four hours.
Boston	90,000	20
Milk River	99,000	45,000
Pecos	105,000	120
Chattahoochee	120,000	45
Colorado	103,000	5

Comparing the results of experiments 1 and 4, Milk and Pecos rivers, it will be seen that the Milk River water prevented to a marked degree the toxic action of the copper, while the results with the Pecos water indicate a much greater toxicity. The amount of copper dissolved by the Milk water was 0.2 parts per million, and by the Pecos 0.5 parts. The total hardness of the Pecos water was the greater, but it was due largely to the incrustants, while the hardness of the Milk water was due to bi-carbonates entirely. It appears, therefore, that carbonates and bi-carbonates prevent the solution of the copper and consequently destroy the efficiency of the canteen to a much more marked degree than do the incrustants.

The Colorado water with some turbidity and a moderate hardness dissolved as much copper and showed as marked a toxic effect as the Boston water would have done under the same circumstances. This water is characterized by the presence of sodium or potassium carbonate equivalent, to about ten parts per million of calcium carbonate. There can be little doubt but that the amount of copper dissolved in this case was due to these alkaline carbonates which dissolved the copper by the formation of soluble double salts. The Chattahoochee dissolved about the same amount of copper as did the Colorado, but the toxic effect was much less. This, I believe to be due to the fact recently pointed out by Sullivan, that mixtures of copper salts and such insoluble silicates as kaolin obey the mass action law in that alkaline and alkaline earth salts are dissolved from the silicates and complex insoluble silicates of copper are precipitated until an equilibrium is established. This equilibrium point Sullivan found to vary

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